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Geology and Economic Resources of the Pennsylvania Portion of the Milford and Port Jervis 15-Minute Quadrangles

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ATLAS 223

Geology and Economic Resources of the Pennsylvania Portion of the Milford and Port Jervis 15-Minute Quadrangles

by **Frank W. Fletcher**
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Hobart and William Smith Colleges

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PREFACE

This report describes the bedrock underlying the Pennsylvania parts of the Milford and Port Jervis 15 minute quadrangles. The history and potential use of these rocks is also presented.

Exposed rocks are approximately 375 million years old and were formed during the Devonian Period of geologic time. All of the rocks are sedimentary in origin and most are shale, siltstone or sandstone.

Much of the text of the report discusses the economic uses of the bedrock and the ground water contained therein. This information is of particular use to mineral industries, professional geologists, urban and rural planners, construction engineers and conservationists.

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GEOLOGY AND MINERAL RESOURCES OF THE PENNSYLVANIA PORTION OF THE MILFORD AND PORT JERVIS 15-MINUTE QUADRANGLES

by

Frank W. Fletcher and Donald L. Wodrow

ABSTRACT

This report describes the bedrock geology of the Pennsylvania parts of the Milford and Port Jervis 15 minute quadrangles. The map area embraces approximately 195 square miles in the Appalachian Plateau Province of northeastern Pennsylvania. The area is characterized topographically by flat-topped, hummocky hills formed as a result of glaciation and subsequent stream dissection of nearly flat-lying strata.

Bedrock of the map area consists of sedimentary strata which strike generally N 35° E. and dip toward the northwest. The rocks range in age from early Middle Devonian (Marcellus Formation) to middle Late Devonian (Lackawaxen Formation) and have a total thickness of approximately 7300 feet. The lower part of the sequence consists of dark-gray, fossiliferous siltstones and shales characterized by ball-and-pillow structures and nodules. The upper part is composed of medium-gray, fine-to-coarse-grained, cross-bedded sandstones and conglomerates and red sandstones and claystones. These beds are plant-bearing and mudcracked.

Low-relief, *en echelon* anticlines, high-angle reverse faults, and well-developed, high-angle joints are the common structures in the area.

INTRODUCTION

PHYSIOGRAPHY

The map area includes all those parts of the Milford and Port Jervis quadrangles which lie in Pennsylvania. The western boundary of the map area is marked by longitude 75° 00′ west and the southern boundary is marked by latitude 41° 15′ north. The Delaware River serves as the northeastern and southeastern borders forming two sides of a roughly triangular-shaped area.

The boundary between the Valley and Ridge and the Appalachian Plateau physiographic provinces lies in the southeast part of the Milford and Port Jervis quadrangles (Figure 1). The Pennsylvania part of the quadrangles lies wholly within the Appalachian Plateau Province. The Appalachian structural front, which separates the Plateau and the Valley

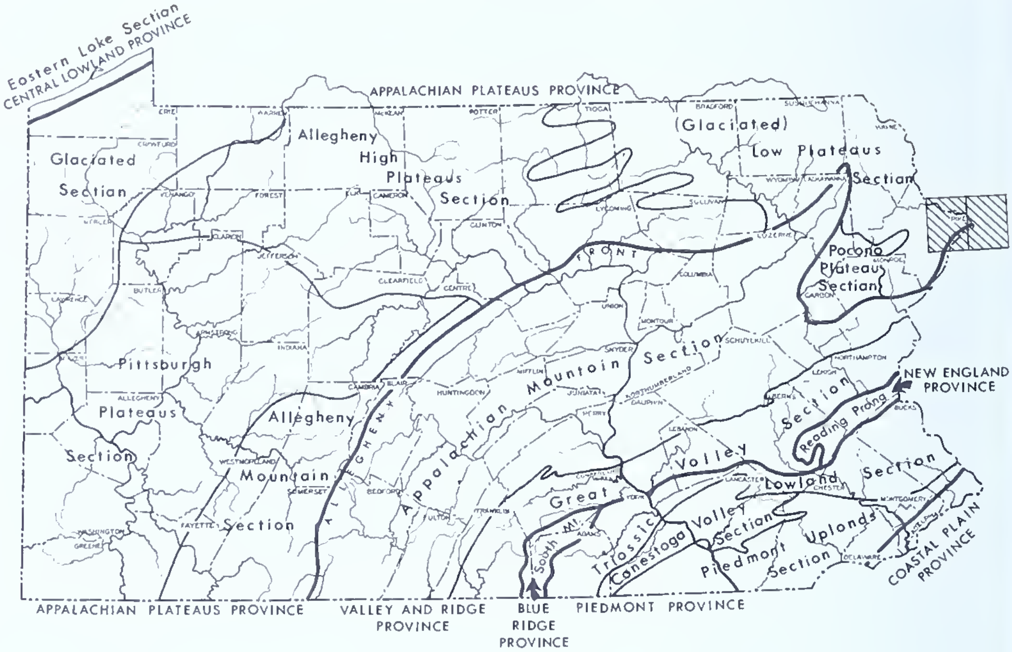


Figure 1. Physiographic subdivisions of Pennsylvania and location of map area.

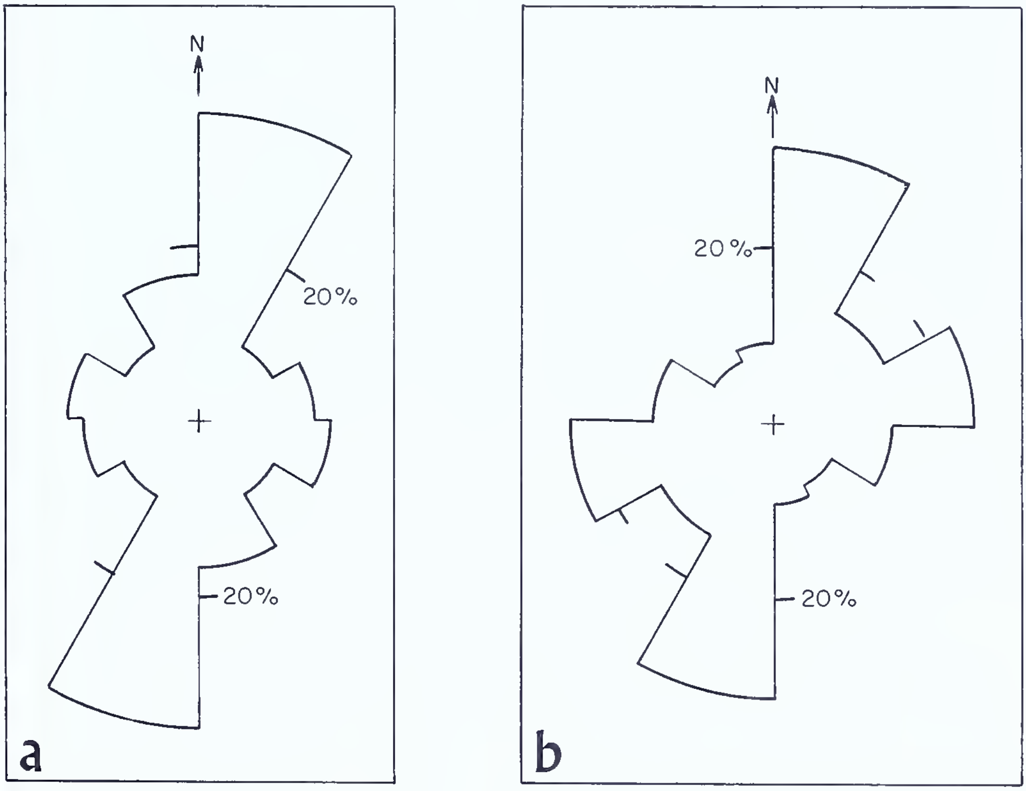
and Ridge, marks the southeastern border of the area studied and it is expressed topographically by steep, southeastward-facing cliffs.

Topography in the most southeasterly part of the area is characterized by a series of indistinct and irregular escarpments that trend northeast-southwest. The escarpments are steep toward the southeast, have gentle northwest slopes, and they are held up by thick siltstones and sandstones. Narrow, irregular valleys underlain by shales separate the escarpments. Topography in the central and northwestern parts of the area consists of flat-topped hills formed on nearly horizontal conglomerates and coarse-grained sandstones. Small kames of unconsolidated or semiconsolidated glacial and glacio-fluvial materials are scattered throughout the mapped area. Hills developed on bedrock commonly reach 1500 feet and a maximum elevation of 1600 feet is attained in the northwest corner of the area. Bedrock is exposed over approximately 10 percent of the region; soil and glacial materials cover the remainder. The most extensive outcrops are found in the steep-sided tributary stream valleys and along the cliffs bordering the Delaware River. Isolated exposures are found on the low escarpments described above. Field tracing of units for more than 400 or 500 feet along strike is impossible in most of the area because of the thick soil cover. Similarly, tracing units on aerial photographs is difficult. However, by combining data from the field with aerial photographs and subsurface data, rock units can be readily identified and mapped in this part of Pennsylvania.

The chief stream in the area is the Delaware River. It flows southeastward past Lackawaxen, Pennsylvania, to Matamoras where it turns toward the southwest and flows past Milford. Major tributary streams join the Delaware River at right angles; smaller streams show a more random tributary pattern. Both major and minor tributary streams exhibit modified rectangular- and trellis-type drainage patterns and their courses are joint controlled (Figure 2).

PREVIOUS WORK

The geology of the Milford region was studied first in 1837 during the First Pennsylvania Geologic Survey under the direction of H. D. Rogers. The final report of 1858 described the geology of the area in general terms. I. C. White's report (1882) on the geology of Pike and



Orientation distribution of stream straightreaches. Data plotted as percent frequencies in 30-degree class intervals. 355 observations

Orientation distribution of joints. Data plotted as percent frequencies in 30-degree class intervals. 79 observations.

Figure 2. Rose diagrams illustrating orientation distributions of joints and straight reaches of streams in the Milford region.

Monroe counties provided the first large-scale geologic map. White's map shows the present study area to be underlain by: Catskill Red Sandstone (youngest), Chemung Flags, Genesee Black Slate, Hamilton Flags, and Marcellus Black Slate (oldest). Although this order of lithologies is reasonably accurate, the subdivisions within the unit White denoted as Catskill Red Sandstone (1882, p. 97-104) required reevaluation by the present writers because they proved to be unrecognizable. The reader will note a broad correspondence between most of the formation boundaries on White's map and those shown on the geologic map accompanying this report. An exception is the upper contact of the Marcellus. White placed this contact 400 feet stratigraphically above its presently recognized position, and he indicated that the upper contact is exposed near the base of the steep cliffs that border U. S. Route 209 between Matamoras and Milford, Pennsylvania. Prosser (1894) and Willard (in Willard, Swartz, and Cleaves, 1939, p. 168) referred to this position of the upper contact of the Marcellus formation. The present writers believe that the upper contact of the Marcellus actually lies east of the cliffs, under the Delaware River flood plain.

White's study was the last in which the geology of this area was mapped, and his map served as the basis for the 1960 edition of the Geologic Map of Pennsylvania (see Gray and others, 1960). Some selected localities in the Milford and Matamoras regions were described by Prosser (1894). His work was based primarily on White's. More recently individual stratigraphic units have been studied such as the "Portage Group" and the Upper Devonian continental rocks by Willard (1935 and 1936 respectively), the Hamilton by Willard and Cleaves (1933), the Portland Point Member of the Hamilton by Cooper (1941) and by McCave (1966 and personal communication), and the Trimmers Rock by Frakes (1963 and 1967).

The present study was conducted during June, July, and August, and September of 1966 as part of a geologic mapping project in northeastern Pennsylvania.

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STRATIGRAPHY

INTRODUCTION

All of the rocks in the map area, with the exception of Pleistocene sand and gravel and recent alluvium, are Middle and Upper Devonian sedimentary strata (Figure 3). The Middle Devonian strata strike approximately N 35° E. and crop out along a narrow band in the most southeasterly part of the area. These layers dip beneath the ground surface toward the northwest. The Upper Devonian rocks are exposed over the rest of the area, are nearly flat-lying and have a total thickness of approximately 6400 feet. Sample data from the W. Hess No. 1 well located near Shohola, Pennsylvania, (2.20 miles north of latitude 41°25′ north and 0.37 miles west of longitude 74° 55′ west) was useful in determination of the precise thickness of units.

MIDDLE DEVONIAN

Onondaga Group and Marcellus Formation

The Onondaga Group and the overlying Marcellus Formation, when taken together, form an excellent datum to which overlying Devonian strata may be referred. Both units occur in eastern, central, and southern Pennsylvania (Gray and others, 1960) and in New York (Broughton and others, 1964). The Onondaga is used as a datum horizon in much of the exploratory drilling for hydrocarbons in the Appalachian Plateau (Wagner, 1959). Similarly, the Onondaga was employed as a datum during the early part of the present investigation. Limestones assigned to the Onondaga Group are exposed along the east bank of the Delaware River in New Jersey (Lewis and others, 1950) and the Marcellus apparently underlies the west side of the Delaware River floodplain, but it is not exposed.

The Marcellus and the Onondaga are present in the Hess No. 1 well (see Plate 2). The Onondaga is found at depths of 6468-6646 feet, and it is made up of approximately 180 feet of very-finely crystalline, dark-gray (N2-N3) limestone with traces of chert. These strata are similar to those in the Buttermilk Falls Formation of Willard (1936), with one distinctive difference. The Buttermilk Falls contains a notable amount of chert; its presumed equivalents in samples from the Hess No. 1 lack chert almost completely. The Marcellus formation is present in the Hess No. 1 well samples at depths 5876-6468 feet, where it is approximately 600 feet thick and is made up of soft, grayish-black (N2-N1) shale. The upper contact of the Marcellus is gradational through 80 feet of strata and the bottom contact is gradational into limey shale through 40 feet of strata.

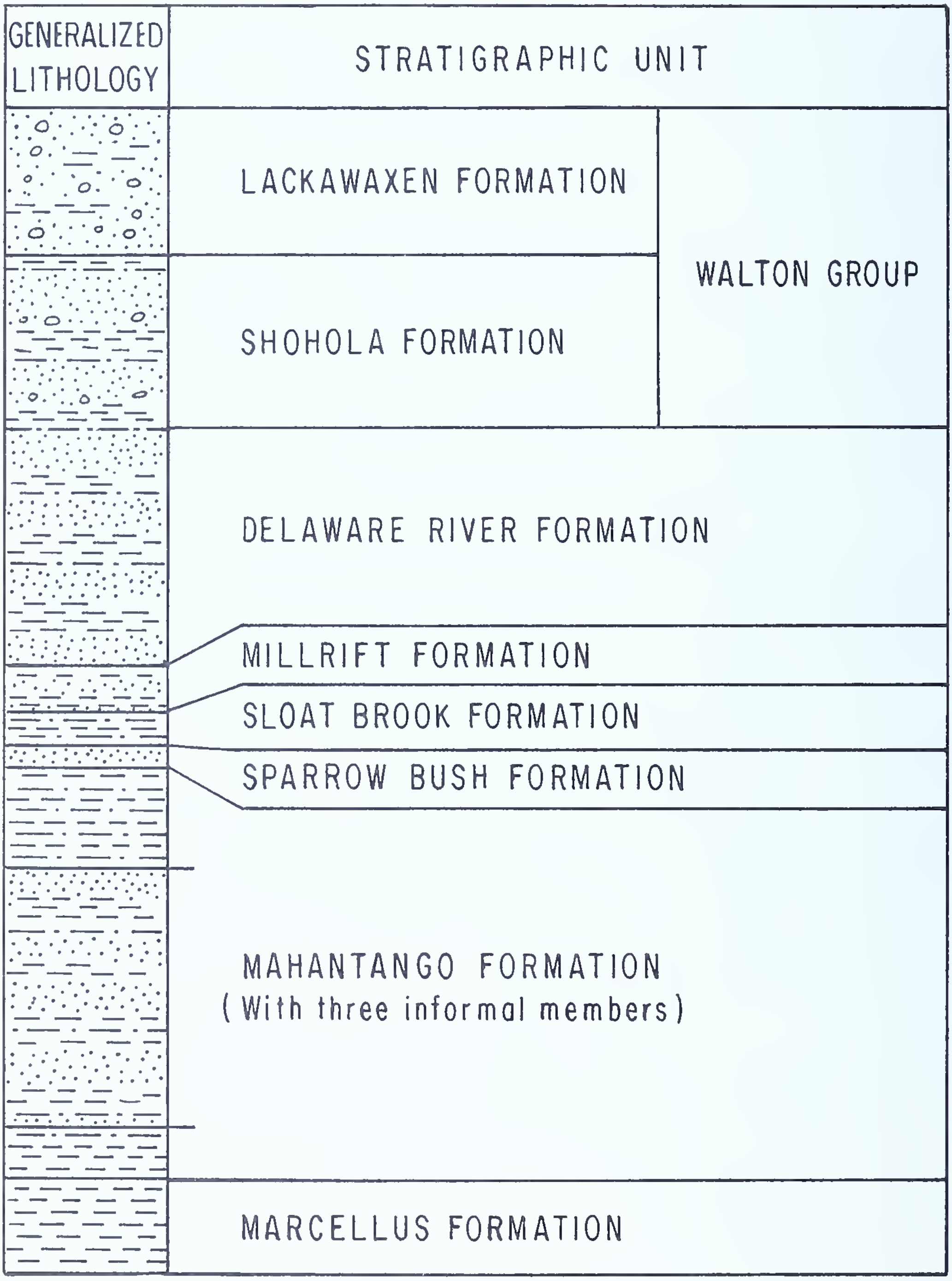

Figure 3. Generalized Middle and Upper Devonian stratigraphic section in Pike County, Pennsylvania.

The writers believe the Marcellus Formation is tectonically thickened near, and east of, the structural front (Figure 1). There, the inferred out-crop belt of the formation is approximately 4000 feet wide. In this area, few rocks are exposed, but the Onondaga strata crop out on the east bank of the Delaware River where they dip to the northwest at 30-50 degrees. Assuming an average dip of 20 degrees under the flood plain, which corresponds to measured surface dips, the thickness is computed to be 1360 feet, more than twice the thickness of the Marcellus in the Hess No. 1 well. The thickening is probably accomplished by faulting and complex folding. This interpretation is suggested by the condition of the Marcellus shales in the well where the shales exhibit a phyllitic appearance. They are crushed and broken in at least two stratigraphic intervals within the formation (see Plate 2, 6000 feet and 6300 feet).

Mahantango Formation

Willard (1935a, p. 205) proposed the term "Mahantango" for the upper of two formations in the Hamilton Group of Pennsylvania. He correlated the Mahantango with the Skaneateles, Ludlowville, and Moscow Formations of the New York Hamilton (see Rickard, 1964). Earlier, White (1882, p. 110) referred to this sequence of rocks in Pike County as the "Middle Hamilton or Hamilton proper." Prosser (1894) described the "Hamilton" in northeastern Pennsylvania as a tripartite unit, but he did not designate the three parts formally. Ellison (1965) studied in detail the stratigraphy and paleontology of the Mahantango in south-central Pennsylvania, and he has described three members in it.

The writers recognize the Mahantango as a formation with three informal members. The basal member is a sequence of silty shales and siltstones; the middle member is characterized by sandstones and siltstones, and shales, siltstones, and sandstones make up the upper member. These subdivisions are similar to subdivisions of the Mahantango recognized elsewhere in Pennsylvania. For example, in Bedford County, Willard (1935b, p. 361) recognized the Gander Run Shale (base), Chaneysville Siltstones, and Frame Shale (top) within the Mahantango. Ellison (1965) later traced these three members throughout central Pennsylvania.

The Mahantango Formation is approximately 2450 feet thick within the area mapped. The Hess No. 1 well unit penetrated the unit at depths 3436-5876 feet (Plate 2). The lower contact is gradational into the Marcellus through 80 feet but the upper contact is sharp.

The upper contact of the Mahantango is marked by the Tully Limestone in most of Pennsylvania; however, limestone characteristic of the Tully are not present in northeastern Pennsylvania. Within the area mapped, the upper contact of the Mahantango is placed at the base of the siltstones, sandstones, and coquinites called here the Sparrow Bush Formation.

The lowest member of the Mahantango is approximately 440 feet thick. It consists of dark-gray (N3-N4), very thin-bedded, fissile shales and siltstones. Individual siltstone beds are laterally persistent and grade upward into shale. The shales weather into small chips that form steep talus slopes at the base of most exposures. The writers found no fossils in these rocks, but Willard (in Willard, Swartz, and Cleaves, 1939, p. 179) reports a few brahchiopods and pelecypods from the lower part of the Mahantango at Stroudsburg, Pa. The lower contact of the Mahantango is not exposed within the area mapped, but it is present in the Hess well at depth 5875 feet. The upper contact of the lowest member of the Mahantango is exposed at elevation 550 feet along a narrow road on the north side of Raymonds Kill gorge. This contact is transitional through 20 feet. Typical features of the lower member may be observed in quarries along U. S. Route 209 southeast of Matamoras (Localities 1, 2, 3, and 4, Plate 1).

The middle member of the Mahantango is approximately 1400 feet thick, and it is present in the Hess No. 1 well at depths of 4055-5432 feet (Plate 2). Exposure and well data indicate that it consists of gray (N3-N5) siltstones, fine-grained sandstones, and shales. The beds are thick, and they are indistinctly defined. Rocks in the middle member characteristically break into blocky fragments due to weathering along closely-spaced joints. Parallel laminae and ripple marks are common in the light-colored (N5) sandstones, but cross-strata are rare. Zones of concretions within which individual concretions are separated from six inches to three feet are scattered through the unit. Nodules occur in association with broken and abraded shells in medium-grained, calcareous sandstones. Shape and size of the nodules vary from discoid, small objects one-sixteenth of an inch to one-quarter of an inch in diameter to irregularly-shaped objects up to one inch on the longest dimension. Concretions are found in strata of the middle member at the Raymonds Kill section in units 8 and 19 and in the Delaware River section in unit 14 (Appendix B). Nodules occur in the strata of the Raymonds Kill section in unit 13 and in the Saw Kill section in unit 3 (Appendix B). "Flow rolls" (Sorauf, 1965) or "Ball and pillow structures" (Potter and Pettijohn, 1963, p. 148) occur in scattered intervals throughout the middle member. They are made up of siltstone or sandstone and they range in shape from small, spheroidal masses to large, spheroidal or rod-shaped masses. None of the ball and pillow intervals proved to be traceable between exposures. These structures occur at the Raymonds Kill, Saw Kill, and Delaware River sections (see Appendix B).

Fossils are common in the middle member of the Mahantango. The following forms have been identified by Woodrow:

Brachiopods:

- *Atrypa "reticularis"* (r)
- *Leiorhynchus globuliforme* (r)
- *Longispina mucronatus* (c)
- *Spinocyrtia granulosa* (c)
- *Tropidoleptus carinatus* (vc)
- *Rhipidomella penelope* (c)
- *Mucrospirifer mucronatus* (vc)
- *Chonetes* sp. (c
- *Mediospirifer* sp. (c)
- *Platyrachella* sp. (?) (r)
- *Protoleptostrophia* sp. (r)
- *Schuchertella* sp. (r)

Pelecypods:

- *Cypricardella tenuistriata* (c)
- *Goniophora* sp. (r)
- *Grammysia* sp. (r)
- *Modiomorphia* sp. (c)
- *Nuculana* sp. (c)
- *Actinopteria* sp. (c)

Trilobites:

- *Greenops boothi* (r)
- *Trimerus dekayi* (r)
- *Phacops* sp. (vr)

Corals:

- *Aulopora* sp. (vr)
- *Pleurodictyum* sp. (vr)
- Rugose corals, 2 types (vr)

Bryozoans:

- *Taeniopora* sp. (vr)
- *Paleochara* sp. (vr)
- *Fenestella* sp. (at least 2) (vr)

Crinoid columnals * (c)
Shell debris (vc)
Plant impressions and carbonized fragments (vc)
Burrows, tracks, and trails (vc)

Fossils occur in shell-rich masses and as widely separated individuals within beds. Fauna representative of the middle member may be examined at the Raymonds Kill section (units 1, 2, and 5), at the Saw Kill section (units 3 and 4), at the Delaware River section (units 14, 15, and 16), and at Localities 5, 6, 7, and 19 (Appendix A).

Within the area mapped, the outcrop belt of the middle member of the Mahantango is approximately one mile wide. Outcrops are developed in the cliffs along the Delaware River opposite the village of Sparrow Bush, New York (see Plate 1). They extend southeast to Matamoras, Pennsylvania, and from there toward the southwest past the borough of Milford. The cliffs parallel to U. S. Route 209 southwest of Matamoras to Milford and beyond are developed in strata of the middle member of the Mahantango.

The upper member of the Mahantango is 450 feet thick. It is made up of interbedded, gray (N3-N4) shales, siltstones, and sandstones; however, shale is the predominant rock type. The upper contact is sharp, and the basal contact is gradational through 100 feet. Sandstones make up approximately one-third of the member. The sandstones have sharp bottom contacts and grade upward into siltstones which, in turn, grade upward into shales. Beds are well defined and sedimentary structures commonly seen in these rocks include: cross-laminae, ripple marks, and ball and pillow structures. Sole markings occur, but they are poorly developed.

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* Specimens of complete crinoids exhibiting extraordinary detail have been collected from middle Mahantango strata at the top of the cliffs at Matamoras by Mr. William Leiser, an Earth Science Teacher in the local High School. Mr. Leiser kindly let the writers examine these specimens; his study of them is nearly complete (1967).

Fossils in the upper member form a population similar to that found in the middle member. Fossils noted by the writers exclusively within the upper member of the Mahantango include: (brachiopods), *Orbiculoidea* sp., *Camarotoechia* sp.; (pelecypods), *Nuculoidea* sp., *Tellinopsis* sp., *Paleoneilo* sp., *Paracyclstirata* sp.; (gastropod), *Cyclonema* sp., and an unidentifiable cephalopod. Cooper (1941) also reported the brachiopod *Pustulatia ("Vitulina") postulosa* from strata exposed in the cliffs opposite Sparrow Bush, N. Y. These strata are here assigned to the stratigraphically highest 75 feet of the upper member of the Mahantango.

UPPER DEVONIAN

Sparrow Bush Formation

The name "Sparrow Bush" is introduced here for the 35 to 45 foot thick sequence of coquinites, fine-grained sandstones, and siltstones directly above the Mahantango Formation. The type section is at the base of the cliffs along the Delaware River opposite the village of Sparrow Bush, New York (see Appendix B). Sparrow Bush strata occupy a very narrow outcrop belt extending southwest from the Delaware River parallel to the structural front and approximately one mile northwest from it (Plate 1).

Coquinites and very fine-grained sandstones make up 70 percent of the Sparrow Bush Formation; siltstones comprise the remainder. These strata are medium gray (N4-N5) to medium-light gray (N6) and they are calcareous. Beds are well defined and of medium thickness. Individual beds of sandstone and coquinite exhibit a sharp bottom contact and a gradational upper contact. Parallel laminae are common, but cross-laminae and ripple marks are rare; sole markings are pooly developed. Fossil preservation, in the form of molds and casts, in Sparrow Bush rocks is excellent. The branchiopods *Leiorhynchus mesacostale* and *Mucrospirifer mucronatus* (?) and crinoid columnals make up the fossil population in which *L. mesacostale* is the most abundant form.

The Sparrow Bush Formation is interpreted as correlative with at least part of the Tully Limestone. The correlation is based on three criteria:

the lithology, stratigraphic position, and paleontology. Sparrow Bush strata are lighter gray and more calcareous than the strata in either the underlying Mahantango or the overlying Sloat Brook Formations. This contrast in lithology indicates a change in the depositional environment comparable to that evidenced by the Mahantango, Tully, and Burket-Harrell elsewhere in Pennsylvania (see Ellison, 1965, p. 37-42; Willard, Swartz, and Cleaves, 1939, p. 217-231) and the Hamilton, Tully, and Geneseo in New York (see Rickard, 1964). Further, the Sparrow Bush occupies a stratigraphic position above the Mahantango comparable to the stratigraphic position above the Hamilton occupied by the sandy equivalent of the Tully in New York, the Laurens. Further, the Sparrow Bush is lithologically similar to the Laurens.

Paleontologic criteria also support the Tully-Sparrow Bush correlation. Ellison (1965, p. 37-39) reports that equivalents of the Tully Limestone in south-central Pennsylvania carry a fauna dominated by *Leiorhynchus mesacostale,* and he noted that this brachiopod first appears in the Tully and its lateral equivalents. In a similar fashion *L. mesacostale* is not found in strata below the Sparrow Bush. Near Stroudsburg, Pennsylvania, Willard (*in* Willard, Swartz, and Cleaves, 1939, p. 177, 208, 214, and 351) reports a sequence of sandstones similar to the Sparrow Bush. These rocks occur above the Mahantango and carry fauna typical of Tully equivalents in New York. Willard suggests the sandstones at Stroudsburg are comparable to the Laurens of New York (Rickard, 1964). In fact, he refers to these sandstones as "Laurens" several times in his report (*in* Willard, Swartz, and Cleaves, 1939, p. 209, 236). Finally, data from Cooper (1941) (personal communication) and L. V. Rickard (personal communication) indicate uppermost Mahantango strata are exposed in the cliffs along the Delaware River opposite Sparrow Bush, New York. There, Cooper noted specimens of the brachipod *Pustulatia* (*"Vitulina"*) *pustulosa* in strata approximately 75 feet below the Sparrow Bush. Cooper says that this form is diagnostic of the uppermost Hamilton in New York and the uppermost Mahantango in Pennsylvania.

The Sparrow Bush is found at depths 3401-3436 feet in the Hess No. 1 well (Plate 2). At this position there are 35 feet of medium-gray to medium light-gray (N5-N6) calcareous, fine-grained sandstones and siltstones. These rocks occur above typical Mahantango strata and below typical Sloat Brook rocks. In a published log the Hess No. 1 well, Wagner (1963) placed the top of the Tully equivalents at depth 3740 feet based on comparison of radioactivity and lithologic logs of several wells in northeastern Pennsylvania and surface data from exposures located approximately 60 miles southwest of the well site. He was unable to use surface information from exposures in the Milford fifteenminute quadrangle because the data represented in this report had not been accumulated at that time.

Sloat Brook Formation

Sloat Brook is introduced here as a stratigraphic name designating a sequence of dark-gray (N3) silty shales, siltstones, and very fine-grained sandstones directly above the Sparrow Bush Formation. The type section is in the west bank of Sloat Brook, a northeasterly-flowing tributary of Saw Kill Creek, between elevations 840 and 900 feet (Plate 1). Exposures on the west shore of the Delaware River at Sparrow Bush, New York (Plate 1) are designated as a reference section. The unit is found in the Hess No. 1 well at depths 3060-3401 feet (Plate 2).

The formation is 340 feet thick. Its basal contact is sharp and the upper contact is gradational through 40 feet of strata into the overlying Millrift Formation. Silty shales make up approximately 50 percent of the formation, siltstones 40 percent, and sandstones the remainder. Beds in the Sloat Brook are thin, well defined, and laterally persistent with the limits of exposures. The siltstones and sandstones exhibit sharp bottom contacts, and they grade upward into finer-grained strata. Cross-laminae and faintly-visible groove casts are common, while convolute bedding is rare. Groove cast orientations are distributed about a mean direction of 75/255° degrees (Figure 4).

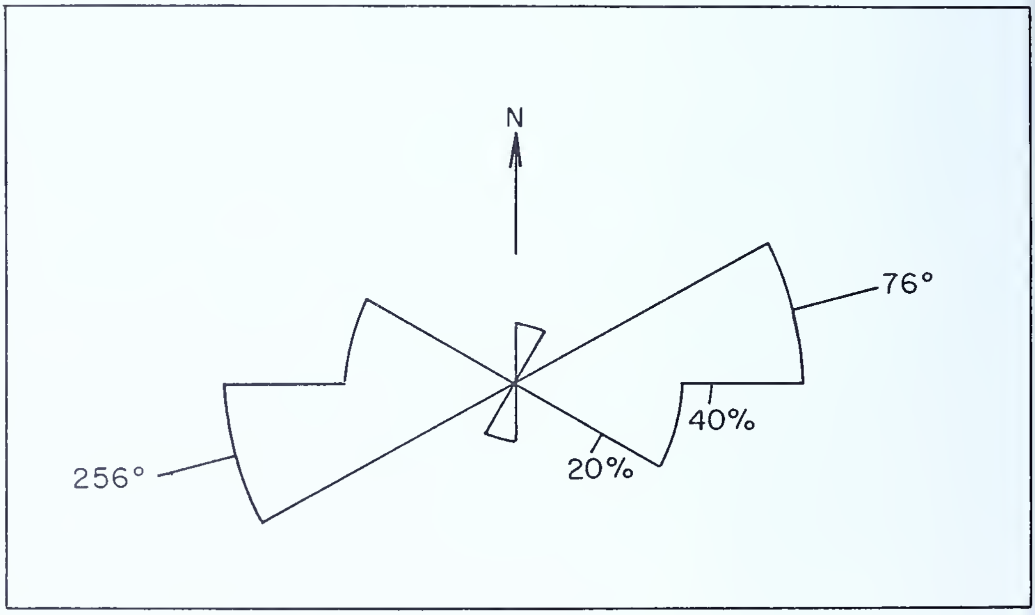


Figure 4. Rose diagram illustrating the distribution and mean of the distribution of groove cast orientations in the Sloat Brook Formation.

Small, thin-shelled pelecypods comprise the Sloat Brook fauna. *Nuculoidea* sp. is common and is found in most beds. *Grammatodon* sp., *Goniophora* sp., *Spathella* sp., and *Actinopteria* sp. (?) also have been identified.

Millrift Formation

Willard (1935a, p. 123) introduced the term "Trimmers Rock" to designate the Upper Devonian clastic sequence directly above the Harrell Shale in central Pennsylvania. Later, Willard (1935b) made the Trimmers Rock a member of the Fort Littleton Formation. Frakes (1963) accepted Willard's redefinition of Trimmers Rock during his study of the non-red Upper Devonian of Pennsylvania. Based on lithology, stratigraphic position, and paleontology, the Millrift Formation is recognized as the stratigraphic equivalents of the Trimmers Rock in the area mapped. The name Trimmers Rock is not used in this area because the rocks of the Millrift exhibit a much wider range of grain size and thus do not look like the Trimmers Rock of central Pennsylvania.

The type section is designated as the exposure on the west bank of the Delaware River at Millrift, Pennsylvania (Plate 1). The exposures begin beneath the Erie-Lackawanna railroad bridge and extend downstream from the bridge abutments for 250-300 yards. Typical features of the Millrift also may be examined at the reference section, the upper part of Sloat Brook and other exposures of Millrift strata are present at Localities 8, 10, and 11 (Appendix A). The formation is noted in the Hess No. 1 well at depths 2530-3060 feet (Plate 2). Both contacts are gradational: the bottom grades into the gray shales of the underlying Sloat Brook Formation through 25 feet and the top grades into the coarser sandstones of the Delaware River Formation through 100 feet. The bottom contact may be examined at the Delaware River section, and the top is exposed, albeit poorly, at Locality 19 (Appendix B).

The Millrift Formation consists of 530 feet of interbedded, fine-grained sandstone, siltstone, and shale. The sandstones are medium-gray (N5-N6) or grayish-blue (5B5/1), the siltstones are gray (N4-N5), and the shales are dark-gray (N3). Sandstones make up 60 per cent of the unit and siltstone and shale the remainder. The sandstones are thin- to medium-bedded and exhibit sharp bottom contacts, poorly-developed sole markings, parallel and cross-laminae, and ripple marks. The upper contact of the sandstones is gradational upward into siltstones and shales. Angular, gray shale clasts are scattered locally through the basal part of some sandstones.

Ball and pillow structures are characteristic of the formation. These range in size from two inches to six feet on the longest dimension. The largest of these structures occurs in zones several feet thick in which the ball and pillows are spheroidal or rod-like masses of fine-grained, laminated sandstone or siltstone. These zones display a chaotic megafabric. A plot of the orientation of the longest dimension of ball and pillow structures in the Millrift Formation indicate a prominent mode in a northeast-southeast direction (Figure 5). The mean orientation for this distribution is in the direction 66/246 degrees.

Invertebrate fossils, though not abundant, are found in many parts of the Millrift. The fauna is made up of pelecypods (which dominate the population), brachiopods, and crinoid debris. The following forms have been identified: (brachiopods), *Tropidoleptus carinatus, Leiorhynchus* sp., *Mucrospirifer* sp.; (pelecypods), *Leptodesma spinigerum* (?), *Paleoneilo* sp., *Sphenotus* sp., *Cornellites* sp., *Grammysia* sp., and *Nuculoidea* sp.; *Bembexia* sp.; *Tentaculites* sp., crinoid columnals, and an unidentifiable trilobite.

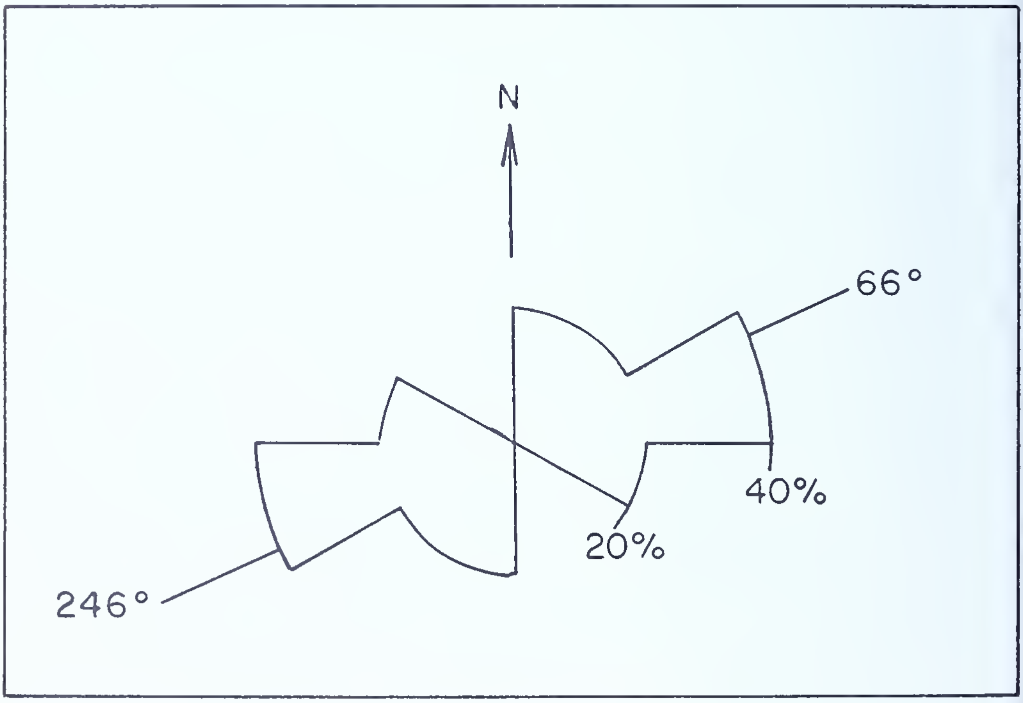


Figure 5. Rose diagram illustrating the distribution and mean of the distribution of ball-and-pillow structure long axes orientations in the Millrift Formation.

Delaware River Formation

The name "Delaware River Flags" was introduced by White (1882, p. 99) for "a series of greenish-gray sandstones and shales . . . exposed along the Delaware River between Narrowsburg and Pond Eddy." White stated that this unit is overlain by the "Montrose Red Shale" and underlain by the "New Milford Red Shale." White's measurements indicated the Delaware River flags to be 1430 feet thick, of which the lower 1000 feet was characterized by the ". . . entire absence of red beds . . ." (1882, p. 99). Thus, White defined originally a unit made up essentially of non-red rocks with red strata above and below.

Prosser (1894) next studied the rocks exposed along the Delaware River and applied the name "Delaware River Flags" to the strata exposed in the cliffs at Hawks Nest, several miles southeast of Pond Eddy, Pennsylvania (Plate 1). These rocks, however, occupy a position stratigraphically below the base of the rocks White designated as Delaware River flags. Willard (*in* Willard, Swartz, and Cleaves 1939) accepted Prosser's definition of the term and designated the cliffs at Hawks Nest as the type section. Willard said that the Delaware River Flags ". . . consist of practically barren, greenish flags devoid of red beds . . ." Willard then stated that the thickness White quoted for the Delaware River Flags, 1430 feet, should be increased by probably 50 percent.

White's definition has not been employed by the writers because it designates an unmappable stratigraphic unit. White stated (1882, p. 99) that most of the rocks in the Delaware River flags are non-red and, further, that the few red beds in the unit are restricted to the uppermost one-third. The writers have found, however, several intervals of red strata scattered through White's type section between Pond Eddy and Shohola at Localities 14, 15, 16, and 17. Red strata are present also in the Hess well in the interval the writers correlate with rocks encompassed by White's Delaware River flags (see Plate 2). Because there is no 1,400 foot interval of non-red strata in the section White designated as the type for his Delaware River Flags, the unit is unmappable as White defined it. Therefore, the writers have redefined the Delaware River as a formation consisting of 1260 feet of interbedded gray (N5-N6) sandstone and siltstone, greenish-gray and olive (5GY and 5Y) shale and claystone, the upper contact of which is drawn at the base of the stratigraphically-lowest red strata in the overlying Shohola Formation. The basal contact grades downward through 100 feet of strata into the underlying Millrift Formation. This definition of Delaware River Formation is essentially that employed by Willard and Prosser, however, the term "flags" has been omitted here because it is not an acceptable lithologic term in the spirit of the Code of Stratigraphic Nomenclature (American Stratigraphic Commission, 1961).

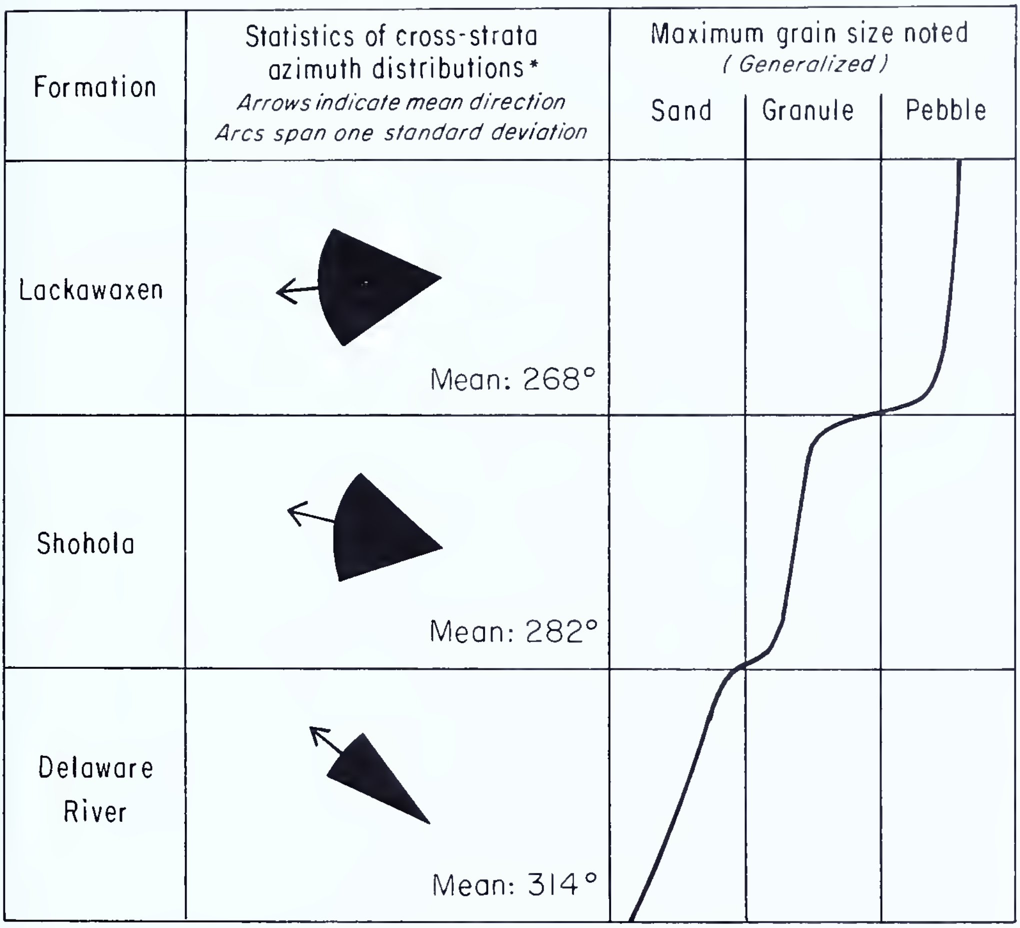
The exposure at Hawks Nest is designated the type section. There, approximately 1000 feet of the Delaware River Formation crops out. The upper contact is exposed at Locality 18 and the lower contact is partly exposed along the pipeline right-of-way at Locality 19 (Plate 1 and Appendix B). Distinctive topography is developed over the strata of the formation consisting of low, linear, southeast-facing cliffs with smooth, northwesterly slopes between. Individual cliffs can be traced topographically for distances of one to three miles. The outcrop belt widens in the Delaware River valley because of a sharp eastward flexure in structural trends (Plate 1).

Sandstone makes up 90 percent of the formation; siltstone, shale, and claystone make up the remainder. The sandstones are calcareous, gray (N5-N6), thick-bedded, and cross-stratified. Sand grain size varies from fine at the base of the formation to medium at the top. Cross-strata are of the trough-type with individual cross-strata one-half inch to three inches thick and individual troughs 15 to 20 feet wide. The distribution of trough-plunge azimuths and cross-strata down-dip azimuths exhibits a mean of 314 degrees (see Figure 6). Other sedimentary structures noted in the sandstones include parting limeations and rib-and-furrow structures.

Shales and claystones in the formation are silty and thin-bedded. These strata are colored olive (5Y4/1-3/1 or 5GY4/1) and gray N3-N5). One sequence of dark-gray (N3) shale in the type section (Appendix B, Hawks Nest Section, unit 47) is noteworthy because it is comparable in lithology and stratigraphic position to a sequence of dark gray shales in the Hess No. 1 well at depths 1950-2000 feet. Based on their lithology and position above the Sparrow Bush Formation (Tully equivalent) these shales at 1950-2000 feet in the Hess No. 1 well (Plate 2) are tentatively identified as equivalents of the Middlesex Formation of New York (see Rickard, 1964).

Fining-upward cycles (Allen, 1965) are common in the Delaware River Formation. Basal rocks in the cycles are sandstones, the lower contacts of which are sharp and undulose. Lenticular intrasparrudites are often developed at the base of these sandstones, and they grade upward into the sandstones. The sandstones, in turn, grade upward into siltstones which grade upward into shales and, at the top, into claystones. These cyclic sequences are 10 to 50 feet thick, and they are similar to cyclic sequences developed in stratigraphically-higher units.

Rocks assigned here to the Delaware River Formation are involved in a facies change as evidenced by color variations. The formation, as it is developed within the area studied, is formed of non-red strata.



* *Statistics determined by Curray's method of analysis (1956)*

Figure 6. Chart illustrating changes in cross-stratification orientations and changes in maximum grain size: Delaware River through Lackawaxen Formations.

Fletcher noted previously (unpublished data), however, that red strata occupy a stratigraphic position equivalent to the Delaware River Formation one to two miles northeast of Hawks Nest (Plate 1). He was unable to trace these red strata into Pennsylvania from New York, and he concluded that the red coloration was lost toward the south. A similar situation involving color changes was noted by Willard in strata he thought to be equivalent to the Delaware River Formation. The strata with which Willard was concerned are exposed southwest of the study area in Monroe County, Pennsylvania. There, Willard attempted to trace a series of red rocks, the Analomink Formation, to the northeast, but he was unable to do so (Willard, Swartz, and Cleaves, 1939, p. 295). Willard projected the Analomink to the Delaware River valley and thought the red rocks of the Analomink should be found in the lower part of the Delaware River Formation. No red rocks occur at this position, however, so he concluded that the red coloration is lost toward the northeast. Thus, the Delaware River Formation, which at its type section is made up of non-red strata, undergoes, at least in part, a green to red color change both toward the northeast and toward the southwest from the area mapped during this study.

WALTON GROUP

Fletcher (1963, p. 38-39) defined the Walton Formation as a sequence of red shales and claystones interbedded with medium- to coarse-grained conglomerates, and greenish-gray sandstones. The type locality of the formation is on the north side of Bear Spring Mountain one mile southeast of Walton, New York. Fletcher traced the formation into the Delaware River valley at Shohola (see Fletcher, p. 36 and 39). In the area mapped Walton is elevated to a group, and includes the Shohola Formation and the Lackawaxen Formation.

Studies by Sutton (1963) and by Fletcher (1963) in adjacent areas of New York State showed that the Walton Formation is equivalent, in part, to the Rhinestreet Formation of western New York. This correlation was established by tracing dark-gray shale members of the Rhinestreet into the type section of the Walton (Sutton, 1963, p. 91). Correlation of the Shohola with the lower part of the Walton of New York is based on Fletcher's (1963) studies. Further indication that this correlation is reasonable comes from data gleaned from the log of the Hess well (Plate 2). Twenty-one feet of gray (N3-N4) shale are found at depths 924-945 feet. Based on their lithology and stratigraphic position, these strata are tentatively identified as the stratigraphic equivalent of the basal member of the Rhinestreet Formation. The dark-gray shales are unique when compared to strata below them for approximately 300 feet below them. Rocks of this type are unknown from higher stratigraphic positions within the area mapped. Further, this dark-gray shale sequence occupies a stratigraphic position approximately 2450 feet above the Sparrow Bush Formation (Tully equivalent) a position analogous to that occupied by the basal member of the Rhinestreet above the Tully in Southeastern New York (see Sutton, 1963, p. 90, Fig. 2).

Shohola Formation

The Shohola Formation was named by Willard (*in* Willard, Swartz, and Cleaves, 1939). He included in it the gray sandstones with red interbeds which crop out at Shohola, Pennsylvania. The same strata had been described previously by White (1882, p. 99) as the Delaware River Flags. The Shohola Formation outcrop belt extends southwest from the Delaware River across the central part of the map area. It is exposed best in Shohola Creek and along the Erie-Lackawanna Railroad between Pond Eddy and Shohola where it is approximately 1100 feet thick. Its lower contact is drawn at the base of the stratigraphically-lowest red strata and the upper contact of the Shohola is marked by the base of the coarse-grained sandstones and conglomerates of the overlying Lackawaxen Formation. This contact is gradational through 100 feet.

The Shohola Formation may be distinguished from the Delaware River Formation on three criteria. First, the Shohola contains red strata, which the Delaware River formation lacks. Second, the sandstones of the Shohola are coarser-grained. Third, the down-dip azimuths of cross-strata and the trough-plunge azimuths of cross-strata are more westerly (282°) in the Shohola than those in the Delaware River Formation (314°) (see Figure 6).

Sandstones dominate in the Shohola; they are medium- to coarse-grained, greenish gray (5GY5/1), and medium gray (N5). They are very thick bedded and exhibit cross-stratification of the trough type. Parting lineations and ripple marks are common; groove casts are rare. Interbeds of red (10R3/4-5R3/2) shale, claystone, and siltstone and very fine-grained sandstone and green (5G4/1-5/1) and gray (N3/N4) shale and claystone make up approximately 30 per cent of the formation. Fine-grained intrasparrudites are found at the base of the sandstones as widely scattered lenses three to four feet thick; rarely do these rock bodies extend laterally for more than a few tens of feet. They are composed of nodule-like clasts of olive-colored sparry material, shale chips, and coarse-grained quartz sand (Table 1).

Table 1. Petrographic data on intrasparrudites from the Shohola Formation

Sample number	Quartz and Quartzites	Calcareous Rock Fragments	Other Rock Fragments	Sparry material including cement and replaced grains	Voids
HC-21	7%	61	15	18	0
HC-192	12	58	12	17	1
HC-197	8	74	7	10	1

The rocks in the Shohola Formation are arranged in fining-upward cyclic sequences 10 to 100 feet thick. Sharp, undulose erosion surfaces mark the base of each cyclic sequence. Basal intrasparrudites grade upward into greenish-gray (5GY) sandstones and they, in turn, grade upward through fine-grained sandstones into red shales and claystones.

The highest rocks in the sequence are green (5G) claystones. Many of the cyclic sequences do not display all of the rock types described; however, the fining-upward grain size and color changes are persistent features. Changes in type of sedimentary structures accompany the grain size and color changes. For example, groove casts are restricted to the base of the intrasparrudite beds and trough cross-strata, parting lineations, and large ripple marks are found in the sandstones and siltstones. Very fine ripples and mudcracks are found in the shales and claystones. Carbonized plant fragments and plant impressions are the only fossils observed in the Shohola. None is sufficiently well preserved to permit identification.

The Shohola Formation is readily mapped across the area because the sandstones form numerous, distinctive ledges in the uplands and boulder fields in the streams valleys. Also, extensive swamps and thick, red soils are developed on the less resistant red strata of the formation. The ledge topography is similar to that developed on the Delaware River Formation, but it is more rugged; further, the highest hills in the area mapped are formed over sandstones in the Shohola.

Lackawaxen Formation

The term "Lackawaxen" was employed by White (1882, p. 100) for a massive conglomerate found in the hills surrounding Lackawaxen village. Willard (*in* Willard, Swartz, and Cleaves, 1939, p. 292-294) included this sequence in his Shohola Formation. The present writers have determined that the rocks White referred to as Lackawaxen are the base of a thick sequence of gray conglomerates, greenish-gray conglomeratic sandstones and fine-grained red strata, which form a mappable rock unit. This rock unit is recognized here as a formation in the Walton Group and approximately 600 feet of strata have been assigned to it within the area mapped. In fact, the unit thickness is probably much greater than 600 feet because reconnaissance studies by the writers indicate that similar rocks are exposed in a belt, many miles wide, north and northwest of the Milford 15-minute quadrangle. Nothing is known of the upper contact of the formation, therefore, but the basal contact of Lackawaxen is gradational through at least 100 feet of strata with the underlying Shohola Formation. The base of the Lackawaxen is arbitrarily drawn at the base of the lowest-mappable conglomerate. This contact is exposed at Locality 21, and it is present in the Hess No. 1 well at depth 174 feet (Plate 2). The outcrop belt of the Lackawaxen extends from the Delaware River valley southwest across the edge of the map (Plate 1). Typical features of the formation may be examined at Localities 22, 23, 24, and 25.

The Lackawaxen Formation is distinguished from the Shohola and Delaware River Formations on the basis of three criteria: maximum grain size in the strata, presence of pink quartz particles, and the mean azimuth of cross-strata orientation distribution. Lackawaxen strata exhibit the coarsest-grained rocks observed in any of the units mapped. Pebbles are common in Lackawaxen strata, but they are extremely rare in the Shohola and Delaware River Formations. Particles of pink to light grayish-red (5R) quartz and quarstite are restricted to the rocks in the Lackawaxen. These grains are a subtle, but important, feature of the gray conglomerate sandstones. Finally, within the Lackawaxen Formation, the mean of the orientation distributions of cross-strata down-dip azimuths and trough-plunge azimuths is 268 degrees. This is the most westerly of the mean azimuths determined for the Delaware River, Shohola, and the Lackawaxen Formation (Figure 6).

Sandstones, conglomeratic sandstones and fine-grained conglomerates with trough-type cross-strata make up approximately 70 percent of the formation. The remainder is siltstone, shale and shalestone. Particles in the conglomerates greater than two millimeters in diameter consist of pink and white quartz and quartzite. The conglomeratic sandstones and coarse-grained sandstones are gray (N5) to light gray (N7). The siltstones and finer-grained rocks are red (10R3/4). These strata are arranged in fining-upward cycles similar to those in the Shohola Formation and the Delaware River Formation. Intrasparrudites are a minor constituent of the cyclic sequences in the Lackawaxen Formation. Fossils are rare. Plant fragments and plant impressions have been noted, but none are sufficiently well preserved for identification.

Based on its stratigraphic position and lithology, the Lackawaxen Formation is thought to correlate with the lower part of the Slide Mountain Formation in eastern New York (see Fletcher, 1963; and Rickard, 1964) and the upper part of the Walton Formation of east-central New York (see Fletcher, 1963).

STRUCTURE

GENERAL

The Pennsylvania parts of the Milford and Port Jervis quadrangles lie on the south flank of a broad, asymmetric synclinorium that plunges toward the southwest (Fletcher, 1963, Fig. 5, p. 33). The maximum dip angle on the south flank, measured at the Appalachian structural Front, is 25 degrees, although dips of 15 degrees are more common. Dips decrease toward the northwest away from the Front. In the northwestern part of the Milford 15-minute quadrangle, the average dip is three degrees or less. Narrow, low-relief anticlines are common in the area studied, but they are little more than small flexures imposed on the northwestward homoclinal dip of the region.

FOLDS

En echelon anticlines are the dominant folds (see Figure 7). The limbs of the anticlines merge directly with the regional, homoclinal dip, so that no synclines are clearly defined. The anticlines are spaced approximately one-half mile apart and are normally four to five miles long. They vary between nearly symmetrical folds with vertical axial planes to highly-asymmetrical folds with axial planes inclined to the northwest. The south limb of an asymmetrical anticline is characteristically the steep limb in which the dip may be as high as 70 degrees. In contrast, the maximum dip measured on the north limb is 15 degrees. Examples of the nearly symmetrical anticlines are at Section 8 (see also Figure 8), and Section 6 (Appendix B). Asymmetrical anticlines are exposed in the Saw Kill section at elevation 580 feet.

The trends of fold axes in the Middle Devonian marine strata display a significant divergence from trends of fold axes in the Upper Devonian continental rocks (Figure 7). The axes of the anticlines in the Mahantango Formation have an average strike of 57 degrees, and they are parallel to the outcrop belt. These folds plunge toward the northeast and the southwest. The trends of the fold axes in the Walton Group, in contrast, have an average orientation of 82 degrees, and they plunge toward the east and the west (Figure 7).

Small, broken anticlines may be observed at two places in the study area, both localities in the Mahantango Formation, in the Raymonds Kill (Unit 6, Appendix B), where the anticline plunges toward 285 degrees, and in the same creek (Unit 5, Appendix B) where the plunge is toward 288 degrees. These are shallow features that are expressed locally only in one bed.

FAULTS

The steep limb of some asymmetrical anticlines is broken by a high-angle, south-dipping reverse fault with the steep south limb thrust toward the fold crest. Vertical displacement ranges between 5 and 15 feet. Accurate measurement of the amount of displacement is difficult because much of it is accommodated along the bedding planes of the steep limb as indicated by slickensides and mineralization. Faults may be examined at Localities 15 and 18 where they are expressed as zones of highly-brecciated and mineralized rock. The fault zones can be mapped for short distances away from the exposures, but mapping them for an extended distance is impossible. Lack of expression of the fault zones

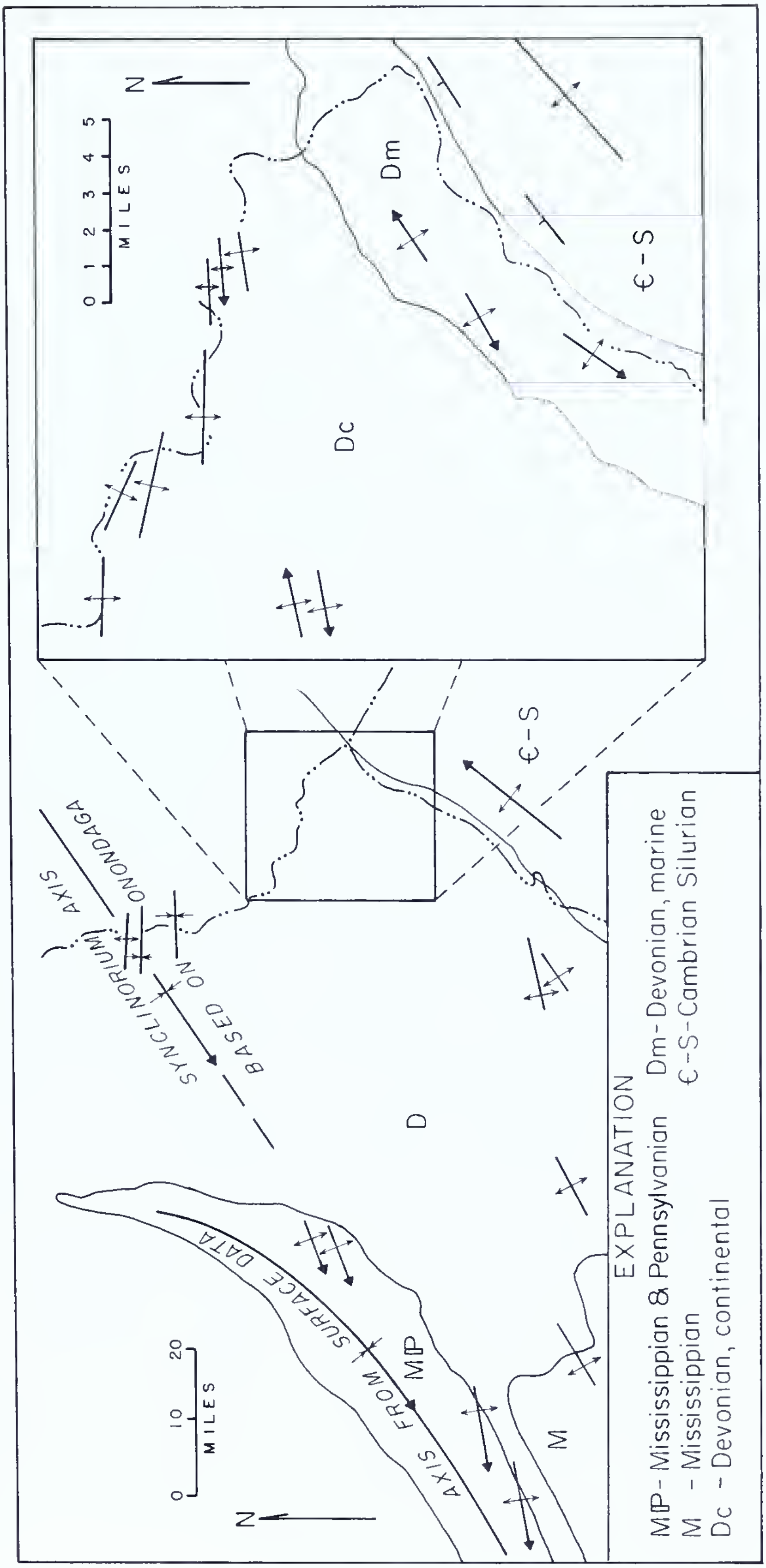


Figure 7. Map of fold axes trends in Milford and adjacent regions.

away from the outcrops is believed to be due to a lack of persistence of the zones.

Bedding-plane faults in the Marcellus Formation are suggested by the phyllitic texture and the presence of calcite and quartz crystals (Plate 2).

JOINTS

Joints are common in all rock units of the area; however, the Middle Devonian strata are more intensely jointed than the Upper Devonian strata. Further, the trend of the joints in the Middle Devonian rocks differs from the trend of the joints in the Upper Devonian rocks. The Middle Devonian rocks are broken by three joint sets, the most prominent of which strikes between 40 and 76 degrees. These joints are closely spaced, and they have irregular traces. Cliffs paralleling the west edge of the Delaware River floodplain are developed along this set. The second major set is made up of more widely-spaced joints that strike between 103 and 146 degrees. This set controls the courses of the major streams in the Milford southeast 7½-minute quadrangle such as Saw Kill, Raymonds Kill and Coneshaugh Creek. A minor, discontinuous joint set form a prominent lineament on aerial photographs of the Milford Devonian strata are not a dominant structure in the area mapped because of the relatively small areal extent of the Middle Devonian outcrop belt.

The joints of the Delaware River Formation and the Walton Group are more widely-spaced and better developed than the joints in the underlying rocks. A major set trends between 2 and 13 degrees and is nearly vertical (Figure 2). The joints in this set have straight traces and have been mineralized. Plumose markings are well developed on their otherwise smooth surfaces. The traces of several closely-spaced joints in this set form a prominent lineament on aerial photographs of the Milford northwest 7½ quadrangle and are distinct features for distances of 12 to 15 miles. Joints in this set also control the drainage pattern in the Milford northeast and northwest 7½ minute quadrangles (Figure 2). Shohola Creek, for example, has incised deeply along joints of this set. A secondary, discontinuous joint set in the Upper Devonian rocks strikes between 82 degrees and 115 degrees, dipping 75 to 90 degrees to the south. These joints, in contrast to the north-south joints, have short, irregular traces and the joint faces are rough and unmineralized.

ORIGIN OF THE STRUCTURES

Sedimentary structures associated with the anticlines of the Walton Group indicate growth of the folds and, in some cases, movement along the faults, concommitant with sedimentation. Strata commonly thin markedly over the crests of the anticlines, and Figure 8 shows that chan-

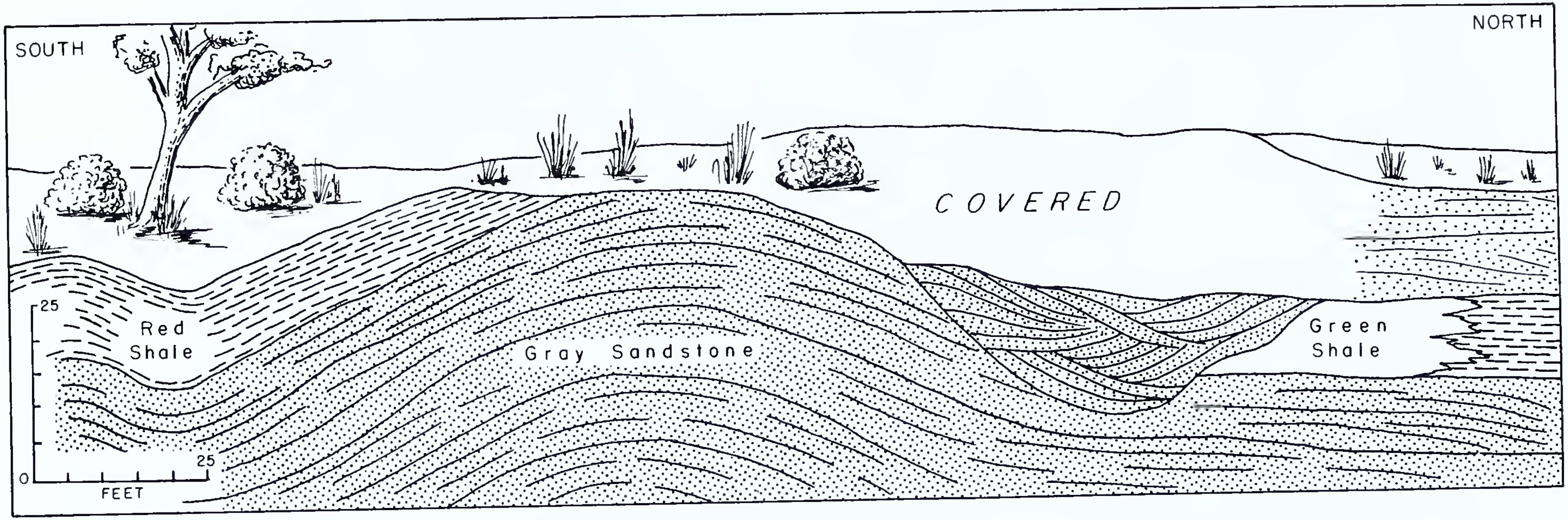


Figure 8. Diagram of anticline in Shohola Creek.

nels are commonly developed adjacent to anticline flanks. Rocks adjacent to the folds also display soft-sediment deformation features and marked facies changes over short distance. Cross-bedding trough axes in the channels show current flow parallel with the fold axes. The geometry of the cross-beds in the channel (i.e., the beds are truncated at their tops and tangential at their bases) shows that the channel was filled in after growth of the adjacent anticline. If the anticline is "unfolded," the cross-beds truncate downward and are tangential upward in contrast to all known cross-stratification (Pettijohn and Potter, 1964). The evidence stated above demonstrates Late Devonian age of the folding.

Evidence of contemporaneous folding and sedimentation indicates that the deformation of the Upper Devonian, and perhaps Middle Devonian, strata is intricately related to events common to late stages of depositional basin filling discussed later. The *en echelon* pattern of fold axes shown in Figure 7 is explained by the strain ellipsoid concept, which has been applied successfully to similar patterns in the Nye-Bowler fault zone of Montana (Badgley, 1965, p. 108-109) and the Kalgoorlic district of Australia (Campbell, 1958). As Figure 9 demonstrates, the fold pattern of the study area is readily explained as the result of right-lateral coupling of the strata along the present course of the Delaware River.

The authors have suggested previously (Fletcher and Woodrow, 1967) that the couple resulted from glide movement toward the basin axis along the stratification planes of the Marcellus Formation in response to overburden weight of the thick molasse sequence deposited on top of the Marcellus during Late Devonian time. Evidence for bedding plane faulting in the Marcellus has been presented. Slope necessary for gliding may have resulted from uplift along the basin margin to the southeast as proposed previously by the senior author (Fletcher, 1964 and 1967). Figure 9 shows that movement of the thrust (or glide) block toward the northwest and the basin axis would produce the right-lateral couple where it tore from a fixed block of strata in the northeast in New York State. The rift zone, presently located along the course of the Delaware River, is marked by the zone of *en echelon* anticlines. Anticlines in the Mahantango Formation may have formed at the same time as a result of crustal shortening of post-Marcellus strata.

The small, broken anticlines in the Mahantango Formation have significantly different orientations from the major anticlines and are believed to have a different origin. Although the evidence of their origin is unclear, they resemble similar folds of the Appalachian Plateau of New York State that have originated as the result of vertically-directed stresses following erosion of overlying beds (Sutton, 1951, p. 404-405).

Investigations of joint patterns indicated that they are commonly the result of complex and polygenetic stresses (Parker, 1942; Hodgson, 1961;

and Nickelsen and Hough, 1967). Study of the joint patterns of an area as small as the Milford region is inadequate for explanation of their causes. Certain relationships are clear, however. The major north-south trending set shown in Figure 2 is parallel to the direction of greatest compression (see Figure 9). The east-west set, on the other hand, is perpendicular to the axis of greatest compression. This relationship, while not conclusive evidence, suggests, at least, a common cause for the joint sets and the pattern of anticlines and faults in the region. If this is true, then the joints may have originated as extension features during Late Devonian deformation in the area. A study of the joints over a larger adjacent region, similar to Parker (1942) and Nickelsen and Hough (1967), would be necessary to determine if this concept can be extended.

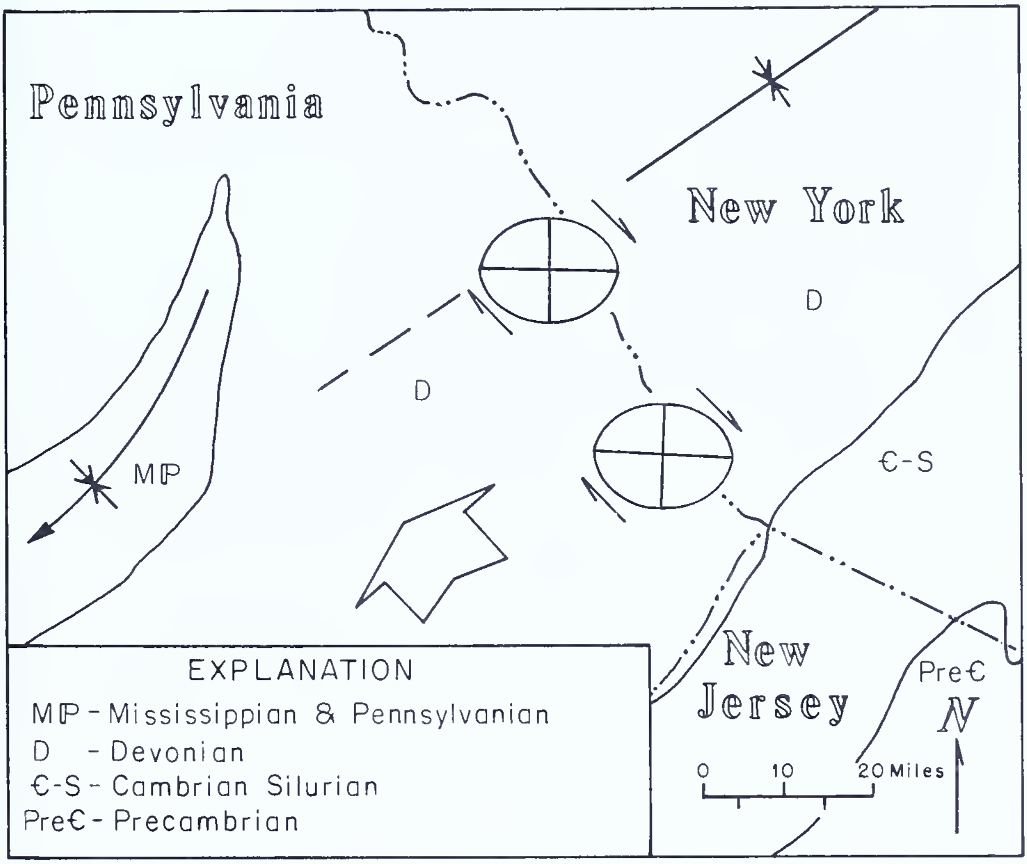


Figure 9. Map showing application of strain ellipsoid to explain en echelon anticlines in Walton Group.

GEOLOGIC HISTORY

MARCELLUS

The change in rock type from limestone in the Onondaga to black shale in the Marcellus apparently indicates modification of an open sea, shallow water environment free of detrital material to an environment characterized by restricted circulation, reducing conditions, and introduction of terrigenously-derived, fine-grained detritals. This interpretation is based on the understanding of black shale depositional environments reported by Dunbar and Rodgers (1957, p. 202-208), Pettijohn, (1957, p. 361-363), and Krumbein and Sloss (1963, p. 565-567). These writers indicate that modern deposition of black muds takes place only at sites of restricted circulation, reducing conditions, and a low rate of clastic influx. That restricted circulation and reducing conditions existed during deposition of the Marcellus sediments is indicated by the presence in them of finely-disseminated pyrite, and organic matter. Concurrent formation of pyrite and preservation of organic matter in modern sediments takes place only at sites of restricted circulation and low Eh (reducing conditions) (Krumbein and Garrels, 1952 and Baas-Becking and others, 1960).

The inhospitability of the Marcellus depositional environment and the lack of appreciable bottom currents operating in it are indicated by the fossils and sedimentary structures in the formation. The writers found no fossils in Marcellus rocks; however, Willard (*in,* Willard, Swartz, and Cleaves, 1939, p. 171) reports a few fossils in the Marcellus in other parts of Pennsylvania. The scarcity of fossils strongly suggests ecological conditions inimicable to bottom-dwelling fauna. Very slow depositional rates are indicated by the absence of coarse-grained clastics, absence of current- or cross-stratification, and development of well-defined fissility in weathered blocks of Marcellus shale (Pettijohn, 1957, p. 593).

Some writers, Ruedemann (1934) and Rich (1951), for example, proposed deposition in very deep water for black shales. The present writers reject this interpretation for the Marcellus rocks exposed in the Milford area because only a modest increase in water depth is indicated by the transitional nature of the contact of the Onondaga and the Marcellus. This contact indicates gradual change from a shallow water marine environment (Onondaga) to a somewhat deeper water marine environment (Marcellus), a change most likely from a few hundred feet depth maximum to, possibly, a one thousand foot depth maximum. The basic change in environment involves the chemistry of the deep water and bottom muds. There is no compelling evidence on which to postulate water depths of several thousand feet.

MAHANTANGO

Paleontologic and sedimentologic characteristics of the Mahantango Formation indicate change of the environments that existed during deposition of the Marcellus. Sediments incorporated into Mahantango strata must have accumulated in marine environments of near-normal salinity, where the water was well-oxygenated and stirred by bottom currents. The profuse and diverse fauna in the Mahantango necessitates this interpretation. Critical indicators include corals, bryozoa, and brachiopods. Modern descendants of these forms prosper only in marine environments of the type described above (Wells, 1957, p. 1087-1089; Osborn, 1957, p. 1109; and Rudwick, 1964, p. 199-200).

The increased effectiveness of bottom currents during deposition of Mahantango strata is specifically evidenced by the presence of rocks in the formation made up of abraded and size-sorted shells,, shell fragments, and quartz granules; by the presence of cross-strata in the arenaceous rocks; and by the great amounts of siltstone and sandstone in the Mahantango. Relatively small quantities of pyrite and organic matter are disseminated through these rocks indicating oxidizing conditions on the sea floor.

Cyclic sequences of strata in the Mahantango Formation illustrate the episodic nature of the deposition of these strata. Apparently, the depositional history of each cycle began with slow deposition in a restricted environment followed by more rapid deposition in environments characterized by freer circulation. Transport of detrital material was toward the southwest and northwest as inferred from ripple mark orientations. Relatively rapid deposition of detrital material on water-laden black muds probably led to local foundering of sandstone and siltstone beds forming ball-and-pillow structures. Seismic tremors may have acted as a triggering mechanism for foundering (Sorauf, 1965, p. 559-563).

SPARROW BUSH

Rocks in the Sparrow Bush Formation illustrate a sharp change in depositional environment from that evidenced by rocks in the older units. Within the Sparrow Bush, beds are well-defined; they are characterzed by laminae parallel to major stratification; and the rocks display medium- to light-gray colors. Fossils in the Sparrow Bush also indicate a definite environmental change because they consist almost exclusively of the brachiopod *Leiorhynchus mesacostale* and a few spiriferid brachiopods. Shells of these forms occur in coquinite beds up to one foot thick. These lithologic and paleontologic features indicate shallow water marine environments where strong bottom currents actively reworked sediments selectively removing fine materials. Thus, the Sparrow Bush is interpreted as a lag deposit of shell-rich, fine-grained sand. Woodrow and Fletcher (1967) have demonstrated that sandstone equivalents of the Sparrow Bush are distributed over most of southeastern New York and much of northwestern Pennsylvania. These sandstones grade laterally into calcareous shales which are interpreted as the material winnowed out of the Sparrow Bush sands. These sands and shales are the stratigraphic equivalents of the Tully Limestone, a unit recognized over much of western Pennsylvania.

SLOAT BROOK AND MILLRIFT

Deposition of the Sparrow Bush sediments was followed by a return to sedimentary environments characterized by restricted circulation. Sloat Brook rocks are finer-grained than those in the Sparrow Bush; they are darker-gray, and they contain a fauna dominated by small pelecypods. Further, the siltstones and sandstones show crudely-graded bedding, sharp bottom contacts, convolute bedding, and cross-laminations. These stratification features are not seen in the Sparrow Bush.

The Sloat Brook rocks are interpreted as deposits formed on a marine shelf of low slope where bottom conditions were inhospitable to most bottom-dwelling fauna. The slope of the depositional surface, whatever, its configuration, was toward the west and southwest. This is indicated by the groove cast orientations (Figure 5) which reflect current flow directions (Potter and Pettijohn, 1963, p. 121-124). The direction of current flow may indicate the paleoslope, or it may reflect the control on bottom current movement caused by subaqueous topography. Based on the delicacy of laminae and lateral persistence of bedding it is inferred that the deposition of muds was slow and interrupted only occasionally by currents transporting sand and silt.

The transitional nature of the Sloat Brook—Millrift contact indicates that depositional environments slowly changed from the restricted circulation conditions existent during emplacement of Sloat Brook sediments. Millrift rocks are characterized by light-gray and gray-blue colors, a diverse and profuse fauna, and by grain sizes in the sand and coarse silt sizes. These features indicate bottom conditions favorable to the development of most benthonic fauna, active currents, and a relatively high rate of sediment influx. The writers conclude that the Millrift strata were deposited on the near-shore part of a marine shelf.

Basin-margin tectonics must have become increasingly effective during the formation of Millrift and younger sedimentary rocks. The stronger imprint of tectonics on sedimentation is illustrated by the steady increase in grain size upsection in this sequence. Further evidence of the increased effect of tectonics is suggested by the presence in the Millrift of numerous ball-and-pillow structures, more than are seen in any of the other stratigraphic unts. Kuenen (1958, p. 20) concluded after a study of similar structures in Holland that they most likely formed by sediment foundering triggered by seismic tremors.

DELAWARE RIVER, SHOHOLA, AND LACKAWAXEN

There is no abrupt change between the Millrift and Delaware River Formation. The writers interpret the changes that are seen in vertical section as indicating a facies change from marine to non-marine strata. For example, the thickness of sandstone beds gradually increases upsection within the Millrift, and the sandstones become increasingly cross-stratified. Gray shales become less common, and their place in the section is taken up by olive and green silty mudstones. Marine fossils gradually diminish in numbers and diversity upsection; none are found in strata assigned to the Delaware River Formation. Plant fragments become increasingly common until, in the Delaware River rocks, they are the only fossils seen. These patterns clearly indicate the trend toward decreasingly marine conditions upsection; the Millrift-Delaware River contact is, therefore, a contact between marine and non-marine rock units.

The higher percentage of sandstone in the Delaware River Formation is interpreted as indicating an increased influx of clastics in response to more intensive tectonic activity in the nearby source area. Paleocurrent data (Fig. 7) indicate the source of these materials lay to the southeast of the Milford region. The thick, cross-bedded, plant-bearing sandstones of the Delaware River Formation strongly resemble deposits formed in channels of a fluvial system that existed on a low alluvial plain close to shore line (See: Allen, 1965b and Woodrow and Fletcher, 1967). Thus, the Millrift-Delaware River Formation sedimentological changes represent the initiation of a major infilling event, during which the rate of sedimentation exceeded the rate of basin subsidence. Imbalance between these two rates, in effect, raised the depositional interface above sea level.

Rocks in the Delaware River Formation are arranged in fining-upward cycles which are devoid of red rocks. These cyclic sequences give way in the overlying Shohola and Lackawaxen Formations to fining-upward cycles which include red rocks. The red coloration of the shales and mudstones apparently formed by oxidation of interfluve muds during times of lowered water table associated with entrenchment of fluvial channels (Fletcher, 1967). Red rocks are present in stratigraphic intervals equivalent to that occupied by the Delaware River Formation northwest and southwest of the Milford region. This pattern of facies change suggests the site of deposition of the Delaware River sediments was occupied by a major distributary system. The water table within the area covered by the distributary system remained sufficiently high to prevent oxidation of the interfluve muds.

The presence of red beds in the Shohola and Lackawaxen Formations indicates a return to conditions favoring water table fluctuations and the persistent grain size increase upsection indicates a steady sedimentary infilling and basinward migration of non-marine depositional environments (Woodrow and Fletcher, 1967). The low alluvial plain represented by strata in the Deleware River Formation was replaced by an upland alluvial plain represented by strata in the Shohola and Lackawaxen Formation. Paleocurrent data (Figure 6) indicate these variations were accompanied by a shift in current flow direction from northwest to west to southwest. Local modifications of the flow pattern formed around the topographic expression of nascent anticlines activated during deposition of the Delaware River, Shohola, and Lackawaxen Formations (Fletcher and Woodrow, 1967).

In summary, deposition in the Milford area during Middle and Late Devonian time was characterized by fluctuations in environmental conditions. The Onondaga, Marcellus, Mahantango, Sparrow Bush, Sloat Brook, and Millrift rocks formed in various marine environments. Restricted circulation conditions characterized deposition of Marcellus, parts of the Mahantango, and Sloat Brook sediments. More open water conditions existed during deposition of most of the Mahantango, Sparrow Bush, and Millrift strata. Open water conditions existed during deposition of the Onondaga and clastic influx was minimal. Basin-filling resulted in non-marine deposition of Delaware River, Shohola, and Lackawaxen strata. A lowland alluvial plan formed at a low elevation (Delaware River Formation) and was replaced by alluvial plains at successively higher elevations (Shohola and Lackawaxen Formations). The non-marine strata were deposited by streams flowing northwest on the lowland alluvial plains. More westerly and southwesterly flowing streams deposited strata on the upland alluvial plain.

ECONOMIC RESOURCES

SANDSTONE

Sandstone has been one of the major economic resources of northeastern Pennsylvania. Large tonnages of flagstone, bulk rock, and ashlar were shipped from quarries along the Delaware River until the end of World War 1 (Stone, 1932). A period of decline in the industry set in at that time. Today the industry is dormant.

Early quarries were developed in rocks of the Lackawaxen, Shohola, and Delaware River Formations in the northern part of the area mapped

(Plate 1). The quarry sites were located near the railroad towns of Lackawaxen, Shohola, Pond Eddy, and Millrift to minimize transportation costs. Potential quarry sites exist, however, at many other locations along the exposure belts of the aforementioned formations. Modern existing highways or ones presently under construction near these sites can serve to ensure low transportation costs. The Delaware River and Shohola Formations offer the most satisfactory units for quarring based on their thickness and their capacity to form steep cliffs along the banks of the major streams.

Sandstones in the Lackawaxen, Shohola, and Delaware River Formations are economically important due to their good weathering properties, hardness, and ease of splitting. Stone cut from these formations was used in many of the local Erie-Lackawanna Railroad bridges and in several homes and public buildings of Milford. Although many of these sandstone blocks have been in place more than 50 years, they show little sign of wear. The Delaware River Formation yields the most highly indurated and, therefore, the hardest rocks in the area mapped. The Lackawaxen sandstones are the least well indurated. Stone one to two inches thick has been cut from the Shohola and Delaware River Formations. Partings develop on laminae in the sandstones and the rock is split along these partings. As the beds are quarried into the hillside, however, the partings become less well defined and the bed assumes a massive character. Large blocks are then cut from these beds. The largest sandstone blocks have been cut from the upper part of the Shohola Formation and from the Lackawaxen Formation. Very thin, decorative sandstone sheets (flagstone and random-shaped building stone) are cut from beds with thin partings and from cross-strata.

Grain-size increases upsection in these strata. That is, the Delaware River Formation contains fine- to medium-grained sandstones, and the Lackawaxen contains coarse-grained sandstones and conglomerates. Most of the sandstones are bluish-gray to gray-green. Red and light-gray coloration is rare.

Joints are developed in all formations. North-south joints form the major set; all other sets are poorly developed and discontinuous. Individual joints in the major set are spaced several feet apart. As a result of these joint sets the rocks break naturally into blocks several feet square and thus, facilitate quarrying operations.

Potential uses for stone cut in the mapped area include: flagstone, ashlar, and crushed stone. The less indurated sandstones of the Lackawaxen and Shohola Formations possibly might be used, when crushed, as a glass sand for the manufacture of colored glass bottles ("glass cans"). The potential for economic development of sandstone resources would be greatest at a site where more than one economic resource might be exploited. For example, a sandstone quarry might be best developed at or near a shale source and, if possible, a sand and gravel source. An operation situated in this fashion could offer for sale stone of all types, sized aggregate for road material and concrete and material for light weight aggregate, brick and tile. Numerous sites of this type might be developed on the exposure belt of the Delaware River, Shohola, and Lackawaxen Formations.

SHALE

Shale from the Shohola and Mahantango Formations is used as a road material throughout the area mapped. This is presently the only economic use of these shales. Shale quarries (Plate 1) are small, and they are operated sporadically. Weathered shales are quarried for road building materials from the basal member of the Mahantango Formation along the base of the steep cliffs that border the west bank of the Delaware River. In the exposures the shales are dark-gray, silty, and laminated. Thin beds of siltstone occur in the unit. The shales break, on weathering, into small randomly-shaped chips. O'Neill and others (1965, p. 301-305) report the results of analyses made on fresh shale from the Mahantango (Table 2). Shohola shales are quarried also for road building materials. The shales are red, silty and thin-bedded. They break into thin, platy fragments one to six inches on the longest dimension. O'Neill and others (1965, p. 300-303) report results of analyses made on shales like those in the Shohola (see Table 3). The sample analysed was obtained from an exposure north of the area mapped.

Potential uses for the shales include: road building materials, berm materials, road metal, and subgrade material for light-duty roads. O'Neill and others (1965) report that as the result of rotary kiln tests the shales may be used as light weight aggregate and in the manufacture of brick and floor tile.

SAND AND GRAVEL

These materials provide a limited resource in Pike County due to their discontinuous distribution. Quarries developed to exploit sand and gravel deposits are few. All are inactive at present.

Pleistocene strata and recent alluvium yield sand and gravel. Pleistocene till and outwash are spread over the entire area mapped. These deposits are commonly 40 to 50 feet thick in stream valleys and ten feet or less over the hill tops. For example, a soil profile developed by drilling along the right-of-way for Interstate Route 84 in the vicinity of the

Table 2. Analysis of gray shale from the Mahantango Formation (from O'Neill and others, 1965, p. 302).

Chemical Analysis

	%
SiO_2	66.90
Al_2O_3	15.70
Fe_2O_3	2.74
FeO	4.10
CaO	.20
Mgo	1.04
K_2O	3.02
Na_2O	.95
TiO_2	.92
L.O.I.	4.41
S	.016
CO_2	1.32
comb. H_2O	2.66
H_2O @ 120°C	.41

Mineralogy: X-ray

	%	Accuracy (±)
Quartz	41	8
Mica	37	8
Kaolinite	12	7
C-V-Mo	1	3
Feldspar	1	3

Other Tests

pH: 7.8
Workability: not plastic, short, fine grit
Water of plasticity %: 18.0
% Drying shrinkage: 4.0
Dry strength: very low

Table 3. Analysis of red shale sample (from O'Neill and others, 1965, p. 300).

Chemical Analysis

	%
SiO_2	62.10
Al_2O_3	18.80
Fe_2O_3	5.80
FeO	2.43
CaO	.08
MgO	1.08
K_2O	4.23
Na_2O	.49
TiO_2	.99
L.O.I.	3.95
S	.016
CO_2	.22
comb. H_2O	3.65
H_2O @ 120°C	.06

Mineralogy: X-ray

	%	Accuracy (±)
Quartz	32	8
Mica	50	10
Kaolinite	5	5
C-V-Mo	2	2
Feldspar	1	2

Other Tests

pH: 6.8
Workability: not plastic, short, fine grit
Water of pasticity %: 19.0
% Drying shrinkage: 4.0
Dry strength: very low

Saw Kill indicates till thickness up to 80 feet in the stream valley. Glacial outwash and alluvium in the Delaware River valley is 100 to 300 feet thick (see Groundwater section).

The size distribution of these materials further limits their usefulness. The tills contain boulders up to 10 feet in diameter in a matrix of fine sand, silt, and clay (Wentworth scale). Most of the till is made up of material in the size ranges greater than sand. Other deposits are composed of materials in the fine sand and silt sizes.

Potential uses of these materials are: filter sand for septic tanks, sized aggregate for subgrade materials and concrete, and sand for beaches of the man-made lakes common in the region.

PEAT

Peat originates from the remains of grass, moss, sedge, and woody plants which grew in areas of poor drainage such as swamps and bogs. The plant remains are preserved because the water of a poorly-drained area excludes oxygen, thus preventing their decay. The depressions in which peat accumulated were formed by glacial scour of pre-glacial valleys. Some subsequent peat accumulation sites were formed by glacial erosion of shale layers, which left large depressions with sandstone bases. In these depressions, characterized by interior drainage of the surrounding watershed, plants grew, died, and accumulated.

Although no peat is presently removed from the Milford and Port Jervis quadrangles, peat is produced in nearby counties. Numerous swamps exist on the high plateau portions of the quadrangles; developed especially over the Delaware River, Shohola, and Lackawaxen Formations. These commonly cover areas from 30 to 100 acres. Some of these bogs are potential peat-producing sites. Cursory examination of some of these swamps indicates that these elongated in a north-to-south direction have the thickest peat accumulation because of the deeper scouring of the bedrock in that direction. High inorganic content mixed with the organic may negate the advantage of the thickness.

PETROLEUM AND NATURAL GAS

A single exploratory well for petroleum and natural gas was drilled in the area mapped. This is the Walker Hess well in Shohola Township. (See Plate 1 for location and Plate 2 for log of well.) The Lower Devonian Oriskany Sandstone was the deepest unit penetrated (Lytle, and others, 1959, p. 40). No hydrocarbons in commercial quantities were located in this well. Subsurface structure and stratigraphy in the post-Silurian rocks apparently was not conducive to accumulation of petroleum and natural gas. Information on the older rocks is not available.

The depth to which wells must be drilled to reach these rocks, however, appears to severely limit the feasibility of testing them extensively.

GROUND WATER

Ground water is water that occupies the zone of saturation; that is, the zone of the earth's crust in which all open spaces are filled with water. The upper surface of the zone of saturation is called the water table. Ground water in the Milford and Port Jervis quadrangles is derived solely from precipitation in the immediate region (Parker and others, 1964, p. 38). The area has a mean annual rainfall of approximately 42 inches (Parker and others, 1964, p. 18). Only a small part of this water reaches the zone of saturation. Most of it runs off as surface water or is returned to the atmosphere by evaporation.

Stratigraphic units that yield collectible quantities of water are called aquifers. The capacity of a unit to act as an aquifer is dependent on the ratio of the volume of openings to total volume of rock (porosity) and the ability of the rock to transmit water (permeability). Factors that control these are grain size, sorting, and the size and nature of fractures. All of the stratigraphic units in the area studied serve as aquifers for the local population.

Water-bearing Rocks

Glacial Deposits

Glacial deposits cover much of the area, especially on the plateau. The deposits range in thickness from a few inches to approximately 300 feet. Till and glacial outwash gravel comprise these deposits. The size sorting of these materials is generally poor, ranging from large boulders up to 10 feet in diameter to silt. This sediment yields only small quantities of water; mostly from shallow, dug wells which extend for only a short depth below the water table (Lohman, 1937, p. 222). The quality is apparently satisfactory for domestic use. These wells, however, are dependent on precipitation and commonly fail during extended dry periods.

Lohman (1937, p. 30) states that the thick deposits of glacial outwash in the Delaware River valley offer potential ground water supplies. The better sorting of these sediments in comparison with the till deposits increases the porosity. Well records show that the glacial outwash varies from a minimum 100 feet at Millrift to a maximum of approximately 300 feet, two miles south of Milford (Lohman, 1937, p. 222).

Sandstone and Conglomerate

Most of the drilled wells in the area mapped obtain water from sandstone; a few wells obtain water from conglomerate. The sandstone-bearing formations are thick, 1100 feet or more, and are large aquifers. Although most of the sandstones are firmly indurated and, thus, have low porosity, they are extensively fractured by prominent joint sets and have well-defined bedding partings. Ground water occupies these fracture systems.

The units with high sandstone-shale ratios, which make good aquifers, are the Lackawaxen, Shohola, and Delaware River Formations. The thin-bedded sandstone of the Delaware River Formation are considered by the drillers to be excellent water-bearing rocks (Lohman, 1937, p. 222). The Delaware River Formation contains a higher percentage of calcium carbonate than the younger sandstone formations, thus water obtained from this formation is hard. Most wells in the sandstones yield from 5 to 25 gallons per minute, although discharges of 100 gallons per minute have been reported from some wells (Lohman, 1937, p. 222).

Shale and Siltstone

Shales do not commonly yield large amounts of ground water because of their small grain size, but the extensive fracture systems in the shale formations of the Milford and Port Jervis quadrangles serve to increase their utility as aquifers. Water is retrieved also from interbeds of coarse siltstone and fine-grained sandstone within the shale formations. The sandy and silty layers of the Millrift Formation, for example, yield up to 30 gallons per minute, whereas the shale layers produce flows of only one to three gallons per minute (Lohman, 1937, p. 223). The Mahantango and Marcellus Formations yield large quantities of water from the sandstone and siltstone interbeds. Extensively fractured parts of these formations also yield large supplies of water. Some wells drilled in the Mahantango produce 100 gallons per minute and wells in the Marcellus 20 to 25 gallons per minute (Lohman, 1937, p. 227-235). Little information is available for the Sloat Brook Formation, although it would probably have a yield similar to the Marcellus.

Quality of Water

Water from the glacial deposits and bedrock contains very little dissolved mineral matter. Water from these deposits is soft. Analyses of water from the area are shown below:

Table 4. Analyses of area water.

(Figures are parts per million.)

	Matamoras, Penna.[1]	Sullivan Co., N.Y.[2]
Silica	11.00	10.20
Iron	.05	.17
Calcium	20.00	17.00
Magnesium	5.50	4.20
Sodium	13.00	4.20
Potassium	.70	.80
Bicarbonate	78.00	66.00
Sulfate	26.00	7.30
Chloride	7.00	2.40
Nitrate	1.80	.30
Fluoride	—	.10
Total Dissolved Solids	127.00	81.00

[1] Lohman, 1947, p. 225, well 498.

[2] Soren, 1961, p. 29, Table 5.

Recreation

Well records and the numerous lakes, swamps, and springs in the area indicate a shallow water table. This makes possible the development of many recreation areas built around small lakes and ponds. Additional lakes and ponds may be developed by damming the through-flowing streams of swamps. The sandstone base of many of the lakes and swamps serve as an excellent foundation for dams. Grouting of prominent joints in these sandstones may be necessary to prevent leakage under the dams.

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APPENDIX A

SELECTED LOCALITIES

(Locality numbers are noted on the geologic map-Plate 1)

MAHANTANGO FORMATION

1. Quarry at base of hill along Pike Co. Rte. 393 on west side of Matamoras, Pa. Base of quarry at elevation 520 feet. Port Jervis southwest 7½-minute quadrangle; 2,100 feet south of lat. 41°22'30" N. and 200 feet east of long. 74°42' 30" W.

MAHANTANGO FORMATION

2. Quarry at base of hill along Pike Co. Rte. 393 on west side of Delaware River 2.3 miles northeast of Milford, Pa. Base of quarry at elevation 420 feet. Milford southeast 7 ½-minute quadrangle; 4,700 feet north of lat. 41°20'00" N. and 2,000 feet west of long. 74° 45' 00" W.

MAHANTANGO FORMATION

3. Quarry at base of The Cliff along U.S. Rte. 209 1.5 miles southwest of Milford, Pa. Base of quarry at elevation 440 feet. Milford southeast 7 ½-minute quadrangle; 4000 feet north of lat. 41°17'30" N. and 2,800 feet east of long. 74°50'00" W.

MAHANTANGO FORMATION

4. Quarry at base of The Cliff along U.S. Rte. 209 2.1 miles southwest of Milford, Pa. Base of quarry at elevation 400 feet Milford southeast 7 ½-minute quadrangle; 1,500 feet north of lat. 41°17'30" N. and 800 feet east of long. 74° 50'00" W.

MAHANTANGO FORMATION

5. Exposure along the south side of secondary road at headwaters of tributary of Conashaugh Creek 1 mile west of U.S. Rte. 209 at elevation 820 feet. Milford southeast 7 ½-minute quadrangle; 6,000 feet south of lat. 41°17'30" N. and 3,800 feet east of long. 74°52'30" W.

MAHANTANGO FORMATION

6. Exposure along north side of secondary road along valley of the Raymonds Kill 0.9 mile northwest of U.S. Rte. 209 at elevation 780 feet. Milford southeast 7 ½-minute quadrangle; 1,500 feet north of lat. 41°17'30" N. and 2,800 feet west of long. 74°50'00" W.

MAHANTANGO FORMATION

7. Exposure on hill side near airway bacon 0.2 mile west of Matamoras, Pa. at elevation 780 feet. Port Jervis southwest 7 ½-minute quadrangle; 2,100 feet south of lat. 41°22'30" N. and 200 feet west of long. 74°42'30" W.

DELAWARE RIVER FORMATION

MILLRIFT FORMATION

8. Exposure on hill side along pipeline right of way 0.3 mile west of the Delaware River and 0.2 mile southwest of Millrift, Pa. at elevation 690 feet. Port Jervis northwest 7 ½-minute quadrangle; 3,500 feet south of lat. 41°25'00" N. and 600 feet east of long. 74°45'00" W.

SLOAT BROOK FORMATION

9. Exposure in cliffs along east side of Deep Brook 2.3 miles north-north-east of Milford, Pa. at elevation 910 feet. Milford southeast 7 ½-minute quadrangle; 6,000 feet south of lat. 41°22′30″ N. and 2,200 feet east of long. 74°47′30″ W.

MILLRIFT FORMATION

10. Exposure on northwest side of pipeline right of way 2.0 miles west of Milford, Pa. at elevation 1,070 feet. Milford southeast 7 ½-minute quadrangle; 2,800 feet south of lat. 41°20′00″ N. and 3,700 feet west of long. 74°50′00″ W.

MILLRIFT FORMATION

11. Exposure on northwest side of pipeline right of way 2.1 miles west of Milford, Pa. and 0.2 mile southwest of Locality 10 at elevation 1,045 feet. Milford southeast 7 ½-minute quadrangle; 3,800 feet south of lat. 41°20′00″ N. and 4,300 feet west of long. 74°50′00″ W.

MILLRIFT FORMATION

12. Exposure of hill summit 0.45 mile west of Cummins Creek and 3.2 miles west of Matamoras, Pa. at elevation 1,090 feet. Milford southeast 7 ½-minute quadrangle; 1,000 feet south of lat. 41°22′30″ N. and 5,400 feet west of long. 74°45′00″ W.

MILLRIFT FORMATION

13. Exposure on hill summit 0.4 mile west of Cummins Creek, 3.2 miles west of Matamoras, Pa. and 0.1 mile south of Locality 12 at elevation 1,080 feet. Milford southeast 7 ½-minute quadrangle; 1,400 feet south of lat. 41°22′30″ N. and 5400 feet west of long. 74°45′00″ W.

SHOHOLA FORMATION

14. Exposure on southwest bank of Delaware River 1.0 mile west of Pond Eddy at elevation 510 feet Milford northeast 7 ½-minute quadrangle; 4,600 feet north of lat. 41°25′00″ N. and 5,400 feet west of long. 74°50′00″ W.

SHOHOLA FORMATION

15. Exposure in cliffs along south side of Erie-Lackawanna Railroad right of way 0.2 mile south of the Delaware River, 3.0 miles southeast of Shohola, Pa. and 0.1 mile west of milepost 102 at elevation 760 feet. Milford northwest 7 ½-minute quadrangle; 7,800 feet south of lat. 41°27′30″ N. and 2,800 feet west of long. 74°52′30″ W.

SHOHOLA FORMATION

16. Exposure in cliffs on east side of unimproved road in valley of tributary of Walker Lake Creek 0.6 miles south of the Delaware River and 3.3 miles southeast of Shohola, Pa. at elevation 800 feet. Milford northwest 7½-minute quadrangle; 440 feet north of lat. 41°25′00″ N. and 4,000 feet west of long. 74°52′30″ W.

SHOHOLA FORMATION

17. Exposure along south bank of the Delaware River 1.0 mile southeast of Shohola, Pa. and directly beneath Bench Mark Z-149 at elevation 460 feet. Milford northwest 7 ½-minute quadrangle; 400 feet north of lat. 41°27′30″ N. and 3,200 feet east of long. 74°55′00″ W.

DELAWARE RIVER FORMATION

SHOHOLA FORMATION

18. Exposure in cliffs along east side of Erie-Lackawanna Railroad right of way 0.3 mile southwest of Pond Eddy, Pa. bridge and 0.2 mile southwest of Milepost 98 at elevation 570 feet. Milford northeast 7 ½-minute quadrangle; 6,800 feet north of lat. 41°25′00″ N. and 3,000 feet east of long. 74°50′00″ W.

MAHANTANGO FORMATION

19. Exposures in Delaware River near northeast bank 0.6 mile southeast of Sparrow Bush, N.Y. at elevation 535 feet. Port Jervis northwest 7 ½-minute quadrangle; 6,500 feet north of lat. 41°22′30″ N. and 2,000 feet west of long. 74°42′30″ W.

SHOHOLA FORMATION

20. Exposure of cliffs on north side of Sanvantine Creek 0.2 mile north of U.S. Rte. 6 and 3.4 miles northwest of Milford, Pa. at elevation 1,060 feet. Milford southeast 7 ½-minute quadrangle; 7,500 feet north of lat. 41°20′00″ N. and 2,000 feet east of long. 74°52′30″ W.

SHOHOLA FORMATION

21. Exposures on both sides of highway U.S. Rte. 6 on hill summit 1.1 miles west of Shohola Falls and 10 miles northwest of Milford, Pa. at elevation 1,265 feet. Milford northwest 7 ½-minute quadrangle; 6,600 feet north of lat. 41°22′30″ N. and 2,600 feet east of long. 75°00′00″ W.

SHOHOLA FORMATION

22. Exposures in cliffs along south side of Erie-Lackawanna Railroad rigth of way 0.2 mile west of milepost 106 and along unimproved road 50 feet west of lumber yard, 0.25 mile west of Shohola, Pa. at elevations 660 feet and 720 feet respectively. Milford northwest 7 ½-minute quadrangle; 6,400 feet north of lat. 41°27′30″ N. and 1,400 feet west of long. 74°55′00″ W.

LACKAWAXEN FORMATION

23. Exposure along northwest side of Pa. Rte. 37, 3.2 miles southwest of Shohola, Pa. at elevation 910 feet. Milford northwest 7 ½-minute quadrangle; 4,600 feet north of lat. 41°25′00″ N. and 2,300 feet east of long. 74°57′30″ W.

LACKAWAXEN FORMATION

24. Small exposure on west side of secondary road over German Hill 2.4 miles southwest of Shohola, Pa. at elevation 1,225 feet. Milford nortwest 7 ½-minute quadrangle; 5,000 feet south of lat. 41°27′30″ N. and 2,400 feet east of long. 74°57′30″ W.

LACKAWAXEN FORMATION

25. Exposures along cliffs on hill on south side of the Delaware River 0.6 mile east of Lackawaxen, Pa. at elevation 925 feet. Milford northwest 7 ½-minute quadrangle; 6,200 feet north of lat. 41°27′30″ N. and 3,800 feet west of long. 74°57′30″ W.

APPENDIX B

DESCRIPTION OF STRATIGRAPHIC SECTIONS

Introduction

The sections described below were measured with a 5-foot Jacob Staff. Elevations were obtained with an aneroid altimeter. Because the strata in the mapped area are nearly horizontal or dip gently and because the most extensive exposures occur in steep, narrow stream valleys, the sections were measured from base to top; that is, oldest rocks to youngest rocks. Although the sections are described below with the youngest at the top, pertinent data, such as fossil zones, that occur within the unit are referred to the unit's base. Comparison of measured thicknesses with calculated thicknesses suggests that the range of error is on the order of plus or minus 5 percent.

Lithologic samples and fossils were obtained from selected units. Particle grain size of rock speciments was compared with standard specimens in which grain size had been carefully measured with a millimeter scale. Color of rock samples was determined by comparison with the Rock Color Chart.. Relative abundance of fossils is noted on the basis of the number of specimens observed as follows: one specimen-present (P), 2 to 10 specimens–common (C), more than 10 specimens–abundant (A), and a unit extremely rich with fossils–very abundant (VA). Preservation of fossils is primarily as molds and casts; some replaced (?) shell material was noted.

SECTION 1–RAYMONDS KILL

Excellent exposures of the lower and middle members of the Mahantango Formation are present in Raymonds Kill. The strata are exposed in the creek bed, especially in the water falls, and in the steep cliffs which form the creek bank. The base of the section is located at a point 1,150 feet south of lat. 41°17′30″ N. and 1,850 feet west of long. 74°50′00″ W. at elevation 400 feet on the Milford southeast 7 ½-minute quadrangle. The section begins at the lowest outcrops in the stream 0.25 miles west of where U. S. Rte. 209 crosses Raymonds Kill. The top of the section occurs at a point where a secondary road, parallel to and east of Raymonds Kill, crosses the stream 750 feet north of lat. 41°17′30″ N. and 3,850 feet west of long. 74°50′00″ W.

Approximately 8 percent of the section is covered, but most of this is restricted to the lowermost 100 feet. Strata at the base of the section dip toward N15°W at 29°. The northwestward dip is generally constant throughout the section, except where it is interrupted by a small anticline in unit 9.

Mahantango Formation
Middle Member

Unit	*Unit Thickness*	*Cumulative Thickness*
1. Sandstone, fine-grained, medium-dark to medium-gray (N4-N5). Blocky weathering with poorly defined beds and disrupted laminations. Scattered nodules and pebbles. Brachiopoda: *Mucrospirifer* sp. (C); Pelecypoda; *Grammysia* sp. (P), *Cypricardella tenuistriata* (P); Echinodermata: crinoid columns (VA)	28.0	1082.7
2. Limestone, medium-dark-gray (N4) to medium-bluish-gray (5 B 5/1). Very hard and massively bedded. Bryozoa: *Prasopora* sp. (P); Brachipoda: *Tropidoleptus* sp. (P), *Mucrospirifer* sp. (C); Echinodermata: crinoid columns (A)	3.5	1054.7
3. Sandstone, fine-grained, medium-dark- to medium-gray (N4-N5). Blocky weathering with poorly defined beds and disrupted laminations. Scattered nodules and pebbles. Brachiopoda: *Mucrospirifer* sp. (P), unidentified spirifer; Echinodermata: crinoid columns (P)	93.0	1051.2
4. Sandstone, fine-grained, medium-dark- to medium-gray (N4-N5). Parallel and cross laminations	41.0	958.2
5. Sandstone, fine-grained, lower 25 feet medium-gray (N5) to pale brown (5 YR 5/2) and upper 285 feet dark- to medium-dark-gray (N3-N4). Thin dark-gray siltstone layers at 123 feet, 140 feet. Pebble beds at 68 feet, 158 feet, 273 feet. Flow roll zones at 95 feet, 105 feet, 182 feet, 210 feet. Syncline axis at 70 feet. Anticline at 95 feet. Fossil zones noted: (base)—Bryozoa: *Fenestella* sp. (C); Anthozoa: rugose coral (P); Brachiopoda: *Tropidoleptus carinatus* (C), *Spinocyrtia granulosa* (C) *Mediospirifer* sp. (C), *?Modiomorpha* sp. (P), *Platyrachella* sp. (P), *Atrypa* sp. (C), *Chonetes* sp. (C), *Mucrospirifer* sp. (C), strophominid (A); Pelecypoda: *Goniophora* sp. (P); Trilobita: unidentified fragments; Echinodermata: crinoid columns. 25 feet above base: Bryozoa: *Fenestella* sp. (C); Brachiopoda: *Atrypa* sp. (C), *Schuchertella* sp. (C), *Mediospirifer* sp. (A), *?Platyrachella* sp. (C); Echinodermata: crinoid columns (C). 68 feet above base: Anthozoa: rugose coral (C); Bryozoa: fenestellid (C); Brachiopoda: small unidentified fragments. 123 feet above base: Bryozoa: fenestellid: Echinodermata: crinoid columns (C). 159 feet above base: Brachiopoda: *Mediospirifer* sp. (C). 218 feet above base: Brachiopoda: *Tropidoleptus carinatus* (A)	31.00	917.2
6. Sandstone, fine-grained, dark-to medium-dark-gray (N3-N4). Parallel laminations above 15 feet. Poorly-defined bedding below. Flow zones 15 feet above base. Small chevron folds to 4 feet above base	124.0	607.2

Unit	*Unit Thickness*	*Cumulative Thickness*
7. Shale, silty, dark gray (N3), very fissile. Flow rolls	20.0	483.2
8. Sandstone, fine-grained, dark-gray (N3). Zones of nodules at 11 feet above base, at 76 feet. Fossils zones: (base) Brachiopoda: *Tropidoleptus* sp. (C), spiriferid (C): Pelecypoda: *?Cornellites* sp. (C); Trilobita: *Trimerus* sp. (C), *Phacops* sp. (P); Echinodermata: Large crinoid columns (A). 36 feet above base: Anthozoa: *Aulopora* sp. (P); Trilobita: *Phacops* sp. (P); Echinodermata: crinoid columns and plates (C). 91 feet above base: Echinodermata: crinoid columns (C). 92 feet above base: Gastropoda: *Bembexia* sp. (C). 136 feet above base: Brachiopoda: unidentified (C), Pelecyopoda: unidentified (P)	246.0	463.2
Lower Member		
9. Claystone, silty, dark-gray (N3). Zone of nodules at 45 feet from base. Flow rolls at 68 feet from base, 84 feet, 100 feet. Small chevron fold at 84 feet from base. Fossil zones: 20 feet above base: Pelecypoda: nuculoid (P), Echinodermata: crinoid columns (C). 50 feet above base: Gastropoda: *Bembexia* sp. (P). 112 feet above base: Brachiopoda: *?Rhipidomella* sp. (P), *Leiorhynchus* sp. (C), *Chonetes* sp. (C). 124 feet above base: Bryozoa: fenestellid (C), Brachiopoda: unidentified (C); Pelecypoda: unidentified (C)	125.00	217.2
10. Covered	59.8	92.2
11. Claystone, slightly silty, dark-gray (N3). Bedding poorly defined. Scattered nodules	5.0	32.4
12. Covered	22.0	27.4
13. Sandstone, fine-grained, medium-dark-to medium-gray (N4-N5). Blocky weathering with poorly defined beds and disrupted laminations. Scattered nodules and pebbles	5.4	5.4

Summary of measurements:

Mahantango Formation (Partial):	1082.7 feet
Middle Member (Partial):	865.5 feet
Lower Member (Partial):	217.2 feet
Total section measured:	1082.7 feet

SECTION 2—SAW KILL

This section in Saw Kill exposes the upper and middle members of the Mahantango Formation. The base of the section is located in Saw Kill at a point 2350 feet south of lat. 42°20′00″ N. and 2850 feet east of long. 74°50′00″ W. at elevation 520 feet in the Milford southeast 7½ minute quadrangle. The base is marked at the topographically lowest exposures in the Saw Kill 0.2 miles northwest of a point where the Milford-Childs State Park road crosses the stream. Beds in the basal unit are inclined toward N14°W at 30°. The uppermost unit of the section is present at a point 900 feet south of lat. 41°20′00″ N. and 2350 feet east of long. 74°50′00″ W. at elevation 765 feet. Approximately 14 percent of the section is covered, restricted mostly to the lowermost 100 feet. A small anticline is present in unit 3.

Mahantango Formation
Upper Member

Unit	*Unit Thickness*	*Cumulative Thickness*
1. Shale, silty, medium-dark-gray (N4), very fissile. Hackly fracture. Brachiopoda: *Chonetes* sp. (C), unidentified brachiopods (C); Echinodermata: crinoid columns (C)	126.0	514.7
2. Shale, dark- to medium-dark gray (N2-N4), very fissile.	18.5	388.7
3. Shale, silty, medium-dark-gray (N4), very fissile. Hackly fracture. Fossils noted 17 feet above base: Echinodermata: crinoid calyx	25.0	370.2
4. Coquinite, sandy, calcareous. Bryozoa: *Taeniopora* sp. (C), *Paleochara* sp. (P), *Fenestella* sp. (A); Brachiopoda: *Mediospirifer* sp. (P), *Spinocyrtia* sp. (C), *Tropidoleptus carinatus* (C), Strophominid (A); Gastropoda: *Bembexa* sp. (P); Trilobita: *Phacops* sp. (P); Echinodermata: crinoid columns (A)	4.7	345.2
Middle Member		
5. Sandstone, fine-grained, medium-dark-gray (N4). Very firmly indurated and massively bedded. Blocky weathering parallel laminations above 68 feet above base. Thin sandy lenses 92 feet above base. Pebble zones 4.5 feet and 68 feet above base. Ripple marks 136 feet and 224 feet above base. Anticline axis 190 feet above base. Fossils zones: 12.5 feet above base: Brachiopoda: *Mucrospirifer* sp. (C): Pelecypoda: nuculoid (C). 127 feet above base: Brachiopoda: *Tropidoleptus carinatus* (P). 130 feet above base: Brachiopoda: spiriferid (C); Echinodermata: crinoid columns (C). 164 feet above base: Brachiopoda: unidentified. 192 feet above base: Brachiopoda: *?Mediospirifer* sp. (P); Echinodermata: crinoid columns (C). 205 feet above base: Anthozoa: *Pleurodictyum* sp. (C), rugose coral (P); Brachiopoda: *Atrypa* sp. (P), *Spinocyrita granulosa* (A), *Longispina mucronatus* (C), *Mediospirifer* sp. (P), *Protoleptostrophia* sp. (C); Pelecypoda: *Grammysia* sp. (P); Echinodermata: crinoid columns (P)	243.0	340.5
6. Covered	70.5	97.5

Unit	*Unit Thickness*	*Cumulative Thickness*
7. Siltstone, medium-gray (N5), slightly fissile. Brachiopoda: *?Mediospirifer* sp. (P); Echinodermata: crinoid columns (C).	27.0	27.0

Summary of measurements:

Mahantango Formation (partial):	514.7 feet
Upper Member (partial):	174.2 feet
Middle Member (partial):	240.5 feet
Total section measured:	514.7 feet

SECTION 3–SLOAT BROOK

This section is located at the head waters of Sloat Brook in the Milford southeast 7½ minute quadrangle. The base of the section is located at the small cliffs along the southwest bank of the stream 2200 feet south of lat. 41°20′00″ N. and 2700 feet west of long. 74°50′00″ W. at elevation 910 feet. The top of the section is located at a point 900 feet south of lat. 41°20′00″ N. and 3900 feet west of 74°50′00″ W. at elevation 1025 feet. Outcrops make up approximately 50 percent of the section. This section noteworthy, however, in that the Sloat Brook Formation, which does not commonly crop out, is here well exposed.

Millrift Formation

Unit	*Unit Thickness*	*Cumulative Thickness*
1. Sandstone, fine-grained, medium-gray (N5) with interbedded dark-gray (N3), fissile shale.	2.8	386.9
2. Covered.	11.5	383.1
3. Sandstone, fine-grained, medium-gray (N5), flow rolls.	5.5	372.5
4. Covered.	12.6	267.1
5. Shale, silty, dark gray (N3). Small, flat-topped ripple marks. Brachiopoda: *Leiorhynchus mesacostale* (P).	15.0	354.5
6. Repeat unit 3 lithology.	1.0	339.5
7. Sandstone, fine-grained, medium-gray (N5) interbedded with medium-dark gray (N) siltstone and silty shale. Brachiopoda: *Lingula* sp. (P).	17.8	338.5
8. Partly covered. Some fine-grained, medium-gray (N5) sandstone float and poor exposure.	20.0	320.7
9. Repeat unit 3 lithology. Brachiopoda: *?Platyrachella mesastrialis* (C), *?Leiorhynchus* sp. (C), *Leptaena* sp. (P), *Tylothyris* sp. (C), spiriferids (C); Pelecypoda: *Sphenotus* sp. (C), *Cornellites* sp. (C), *Leptodesma* sp. (C) *Grammysia* sp (C), *Nuculoidea* sp. (A), *Goniophora* sp. (P); Gastropoda		

Unit	*Unit Thickness*	*Cumulative Thickness*
Bembexia sp. (C); Trilobita: *Trimerus* sp. (P); Echinodermata: crinoids (A).	10.0	300.7
10. Sandstone, fine-grained, medium-gray (N5). Flow rolls in lower 2 feet.	10.7	290.7
11. Covered. Interval includes part of the Sloat Brook Formation as well as the Millrift Formation. Some fine- to medium-grained, medium-gray (N5) sandstone float.	280.0	280.0

Sloat Brook Formation

Unit		
1. Siltstone, dark-gray (N3) very fissile. Lower 7.2 feet partly covered. Pelecypoda: *Grammsyoidea* sp. (C).	62.0	234.6
2. Sandstone, fine-grained, medium-dark gray (N4), poorly cross-bedded.	6.0	172.6
3. Covered.	83.5	166.6
4. Siltstone, dark-gray (N3), very fissile. Pelecypoda: *Actinopteria* sp. (C), *Cornellites* sp. (C), *Spathella* sp. (C).	55.8	83.1
5. Shale, slightly silty, dark-gray (N3), very fissile, scattered lenses 2 to 3 inches thick of siltstone. Brachiopoda: Lingula ap.; Pelecypoda: *Nuculoidea* sp. (A), *Grammatodon* sp. (P).	27.3	27.3

Summary of measurements:

Millrift Formation (partial):	386.9 feet
Sloat Brook Formation (partial):	234.6 feet
Total section measured:	621.5 feet

SECTION 4—DELAWARE RIVER

This section, along the Delaware River between Matamoras and Millrift, Pa., contains the most complete and extensive exposures of the Millrift, Sloat Brook, and Sparrow Bush Formations and the upper member of the Mahantango Formation in the area mapped. The basal units are exposed in isolated outcrops on the east bank of the Delaware River 0.6 mile southeast of Sparrow Bush, N. Y. at 6500 feet north of lat. 41°22′30″ N. and 2000 feet west of long. 74°42′30″ W. at elevation 535 feet on the Port Jervis 7½ minute quadrangle. The section continues in the steep cliffs on the west side of the Delaware River 1.1 miles southeast of the Erie-Lackawanna railroad bridge and then along the railroad to a point 0.1 mile south of the railroad crossing in Millrift at a point 2950 feet south of lat. 41°25′00″ N. and 1450 feet east of long. 74°45′00″ W. at elevation 490 feet.

Approximately 60 percent of the section is outcrop. The upper member of the Mahantango Formation is least well exposed. The type section of the Sparrow Bush Formation is present in the cliffs on the west side of the river opposite the main house of Eddy Farm and the town of Sparrow Bush, N. Y.

Millrift Formation

Unit	*Unit Thickness*	*Cumulative Thickness*
1. Sandstone, fine-grained, greenish-gray (5 GY 5/1), siltstone and shale, medium-dark gray (N4) to greenish-gray (5 GY 5/1). Brachiopoda: *Leiorhynchus globuliforme* (P); Pelecypoda: *Leptodesma* sp. (P), *Lepidoleptus* sp. (P); Gastropoda: *Bembexia* sp. (C); Peteropoda: *Tentaculites* sp. (P) Trilobita: unidentified (P): Echinodermata: crinoid columns (A)	10.9	267.3
2. Covered	34.0	248.3
3. Siltstone and shale, medium-dark-gray (N4), flow rolls.	8.5	214.3
4. Sandstone, fine-grained, siltstone, and shale, greenish-gray (5 GY 5/1) to medium-dark-gray (N4). Irregular bedding	27.8	205.8
5. Sandstone, fine-grained, medium-dark- (N4) to medium-gray (N5). Faint cross-bedding, oscillation ripple marks	19.0	178.0
6. Siltstone, shale, and fine-grained sandstone, medium-dark- (N4) to medium-gray (N5). Thin-bedded	7.2	159.0
7. Coquinite, sandy and pebbly. Pelecypoda: *Sphenotus* sp. (C), *Paleoneilo* sp. (C)	0.4	151.8
8. Siltstone, shale, and fine-grained sandstone, medium-dark- (N4) to medium-gray (N5). Thin-bedded	5.2	151.4
9. Covered	1.5	146.2
10. Sandstone, fine-grained, medium-dark- (N4) to medium-gray (N5), cross-bedded	2.8	144.7
11. Siltstone and shale, medium-dark-gray (N4), ripple marks	2.2	141.9
12. Sandstone, fine-grained, and shale, medium-dark-gray (N4), flow rolls	8.2	139.7
13. Siltstone and shale, medium-dark-gray (N4), ripple marks	8.0	131.5
14. Sandstone, fine-grained, and shale, medium-dark-gray (N4), flow rolls	5.5	123.5
15. Siltstone and shale, medium-dark-gray (N4)	0.3	118.0
16. Sandstone, fine-grained, medium-dark- (N4) to medium-gray (N5), cross-bedded and platy bedding. Some inter-bedded thin gray shale	1.1	117.7

Unit	Unit Thickness	Cumulative Thickness
17. Siltstone and shale, medium-dark-gray (N4)	2.0	116.6
18. Sandstone, fine-grained, medium-dark- (N4) to medium-gray (N5), cross-bedded and platy bedding. Some inter-bedded thin gray shale	1.2	114.6
19. Covered	20.0	113.4
20. Sandstone, fine-grained, medium-dark- (N4) to medium-gray (N5), cross-bedded and platy bedding. Some inter-bedded thin gray shale. Flow rolls	5.0	93.4
21. Sandstone, fine-grained, medium-dark- (N4) to medium-gray (N5), cross-bedded and platy bedding. Some inter-bedded thin gray shale	3.2	88.4
22. Sandstone, fine-grained, medium-dark- (N4) to medium-gray (N5), cross-bedded and platy bedding. Some inter-bedded thin gray shale. Flow rolls	5.4	85.2
23. Shale, silty, medium-dark-gray (N4), fissile	5.5	79.8
24. Sandstone, fine-grained, medium-dark- (N4) to medium-gray (N5). Faint cross-bedding, oscillation ripple marks	8.0	74.3
25. Siltstone and shale, medium-dark-gray (N4)	1.2	66.3
26. Sandstone, fine-grained, medium-dark- (N4) to medium-gray (N5), cross-bedded	0.4	65.1
27. Siltstone and shale, medium-dark-gray (N4)	0.5	64.7
28. Sandstone, fine-grained, medium-dark gray (N4)	0.3	64.2
29. Siltstone and shale, medium-dark-gray (N4)	0.3	63.9
30. Sandstone, fine-grained, medium-dark-gray (N4)	0.2	63.6
31. Siltstone and shale, medium-dark-gray (N4)	1.6	63.4
32. Sandstone, fine-grained, medium-dark-gray (N4)	0.3	61.8
33. Siltstone and shale, medium-dark-gray (N4)	0.3	61.5
34. Sandstone, fine-grained, medium-dark-gray (N4)	0.5	61.2
35. Siltstone and shale, medium-dark-gray (N4), ripple marks	7.0	60.7
36. Sandstone, fine-grained, medium-dark-gray (N4). Flat-topped ripple marks. Plant fragments	0.4	53.7
37. Siltstone and shale, medium-dark-gray (N4)	0.8	53.3
38. Sandstone, fine-grained, medium-dark-gray (N4)	2.4	52.5
39. Siltstone, shale, and fine-grained sandstone, medium-dark- (N4) to medium-gray (N5). Thin bedded. Scattered nodules. Flow rolls	1.3	50.1
40. Sandstone, fine-grained, medium-dark-gray (N4). Wavy laminae	1.0	48.8

Unit	Unit Thickness	Cumulative Thickness
41. Siltstone and shale, medium-dark-gray (N4).........	0.8	47.8
42. Sandstone, fine-grained, medium-dark-gray (N4). Pelecypoda: *Leptodesma* sp. (P), *Paleoneilo* sp. (C)......	2.1	47.0
43. Siltstone and shale, medium-dark-gray (N4).........	0.7	44.9
44. Sandstone, fine-grained, medium-dark- (N4) to medium-gray (N5). Faint cross-bedding, oscillation ripple marks....................................	3.0	43.9
45. Siltstone and shale, medium-dark-gray (N4).........	0.3	41.2
46. Sandstone, fine-grained, medium-dark-gray (N4), laminations. Pelecypoda: *?Actinopteria* sp. (C)........	1.3	40.9
47. Sandstone, fine-grained, and shale, medium-dark-gray (N4), flow rolls...............................	3.8	39.6
48. Sandstone, fine-grained, medium-dark-gray (N4)	0.4	35.8
49. Siltstone and shale, medium-dark-gray (N4).........	1.3	35.4
50. Sandstone, fine-grained, and shale, medium-dark-gray (N4), flow rolls. Plant fossils.....................	1.9	34.1
51. Siltstone and shale, medium-dark-gray (N4).........	1.0	32.2
52. Sandstone, fine-grained, medium-dark-gray (N4).....	1.0	31.2
53. Siltstone and shale, medium-dark-gray (N4).........	0.7	30.2
54. Sandstone, fine-grained, medium-dark-gray (N4).....	0.4	29.5
55. Siltstone and shale, medium-dark-gray (N4). Pelecypoda: unidentifiable..........................	1.4	29.1
56. Sandstone, fine-grained, medium-gray (N4). Echinodermata: crinoid columns (C).....................	0.4	27.7
57. Siltstone and shale, medium-dark-gray (N4).........	1.2	27.3
58. Sandstone, fine-grained, and shale, medium-dark-gray (N4), flow rolls. Groove casts.....................	0.8	26.1
59. Shale, silty, medium-dark-gray (N4), fissile. Irregular bedding....................................	1.3	25.3
60. Sandstone, fine-grained, and shale, medium-dark gray (N4), flow rolls...............................	2.7	24.0
61. Sandstone, fine-grained, medium-gray (N5). Small amount of interbedded gray shale and siltstone. Convolute bedding and groove casts..................	21.3	21.3
Sloat Brook Formation		
1. Shale, silty, medium-dark-gray (N4). Minor amount of Interbedded fine-grained gray sandstone. Groove casts.	73.7	373.1
2. Covered..	103.5	299.4
3. Sandstone, fine-grained, medium-dark-gray (N4), ripple marks................................	4.7	195.9

Unit	*Unit Thickness*	*Cumulative Thickness*
4. Covered	14.8	191.2
5. Sandstone, fine-grained, medium-dark-gray (N4), ripple marks. Groove casts	2.0	176.4
6. Siltstone and silty shale, medium-dark- (N4) to medium-gray (N5), platy laminae. Pelecypoda: unidentified.	9.7	174.4
7. Sandstone, fine-grained, medium-dark-gray (N4) ripple marks. Bottom contact is sharp top contact is gradational with unit 6	0.4	164.7
8. Siltstone and silty shale, medium-dark- (N4) to medium-gray (N5)	1.7	164.3
9. Sandstone, fine-grained, medium-gray (N5). Bottom contact is sharp; top contact is gradational with unit 8.	0.5	162.6
10. Sandstone, fine-grained, and siltstone, medium-dark-gray (N4). Indistinct bedding and flow rolls	2.0	162.1
11. Sandstone, fine-trained, medium-gray (N5). Flow rolls.	1.5	160.1
12. Shale, silty, medium-dark-gray (N4)	8.2	158.6
13. Sandstone, fine-grained, medium-dark-gray (N4), ripple marks. Parallel laminae at base. Cross-bedded at top. Bottom contact is sharp; top contact gradational with unit 13	1.2	150.4
14. Sandstone, fine-grained, medium-gray (N5). Bedding is thin and undulose	2.1	149.2
15. Sandstone, fine-grained, medium-dark-gray (N4), ripple marks	1.8	147.1
16. Sandstone, fine-grained, and siltstone, medium-dark-gray (N4)	8.7	145.3
17. Sandstone, fine-grained, medium-dark-gray (N4), parallel laminae	3.7	136.6
18. Sandstone, fine-grained, and siltstone, medium-dark-gray (N4). Indistinct bedding and flow rolls	3.9	132.9
19. Sandstone, fine-grained, medium-dark-gray (N4), parallel laminae	2.6	129.0
20. Sandstone, fine-grained, and siltstone, medium-dark-gray (N4)	3.5	126.4
21. Interbedded siltstone and fine-grained sandstone, medium-dark-(N4) to medium-gray (N5). This interval occurs at steep, virtually inaccessable cliffs. It was not studied in detail and thickness is estimated	90.0	122.9
22. Sandstone, fine-grained, medium-gray (N5)	18.0	32.9
23. Siltstone and silty shale, medium-dark- (N4) to medium-gray (N5)	0.2	14.9

Unit	*Unit Thickness*	*Cumulative Thickness*
24. Sandstone, fine-grained, medium-dark-gray (N4), parallel laminae	1.7	14.7
25. Siltstone and silty shale, medium-dark- (N4) to medium-gray (N5)	0.2	13.0
26. Sandstone, fine-grained, medium-dark-gray (N4), parallel laminae	7.1	12.8
27. Sandstone, fine-grained, medium-gray (N5)	2.6	5.7
28. Claystone and siltstone, medium-dark-gray (N4), irregular weathering, fossiliferous	3.1	3.1
Sparrow Bush Formation		
1. Sandstone, fine-grained, medium-gray (N5). Bottom contact sharp; top contact gradational with unit 28 of Sloat Brook Formation. At top: Brachiopoda: *Leiorhynchus mesacostale* (VA)	2.3	41.2
2. Claystone and siltstone, medium-dark-gray (N4), irregular bedding, fossiliferous. Blocky weathering	3.6	38.9
3. Sandstone, fine-grained, medium-gray (N5). Groove		
3. Sandstone, fine-grained, medium-gray (N5). Groove casts	1.2	35.3
4. Interbedded siltstone and fine-grained sandstone, medium-dark-(N4) to medium gray (N5). Fossiliferous zone 8 feet above base	17.1	34.1
5. Sandstone, fine-grained, medium-gray (N5), flow rolls, ripple marks. Very fossiliferous: *Leiorhynchus mesacostale* (VA). This is a very distinctive unit and is unlike any bed above or below. It is located on the west bank of the Delaware River directly opposite the main house of Eddy Farm	17.0	17.0
Mahantango Formation		
Upper Member		
1. Interbedded siltstone and fine-grained sandstone, medium-dark- (N4) to medium-gray (N5). Pebbles at 7.5 feet above base	14.7	828.8
2. Interbedded siltstone and fine-grained sandstone, medium-dark- (N4) to medium-gray (N5). Flow rolls, ripple marks	5.3	814.1
3. Interbedded siltstone and fine-grained sandstone, medium-dark- (N4) to medium-gray (N5). Four feet above base: Anthozoa: rugose corals (C): Brachiopoda: *Camarotoechia sappho* (P); Pelecypoda: *?Actinopteria* sp. (A), *Paracyclas lirata* (P); Gastropoda: *Bembexia* sp. (P).	10.0	808.8
4. Shale and claystone, medium-dark-gray (N4), shale is partly silty and very fissile in places. Ripple marks	31.7	798.8

Unit	*Unit Thickness*	*Cumulative Thickness*
5. Interbedded siltstone and fine-grained sandstone, medium-dark-(N4) to medium-gray (N5)	11.0	767.1
6. Sandstone, fine-grained, medium-gray (N5), cross-bedded. Scattered thin gray shale layers. Ripple marks. Fossil zone noted: 2 feet below top: Brachiopoda: *Tropidoleptus.* sp. (A)	18.8	756.1
7. Shale and claystone, medium-dark-gray (N4), shale is partly silty and very fissile in places. Some cross-bedding, ripple marks. Brachiopoda: *Chonetes* sp. (C), *Tropidoleptus* sp. (C): Echinodermata: crinoid columns. (C)	17.0	737.3
8. Sandstone, fine-grained, medium-dark- (N4) to medium-gray (N5), faint laminae, flow rolls	3.8	720.3
9. Shale and claystone, medium-dark- gray (N4), shale is partly silty and very fissile in places	47.8	716.5
10. Covered. Thickness estimated	360.0	668.7
11. Siltstone, medium-dark-gray (N4), thin irregular beds, blocky weathering. Scattered nodules. Brachipoda: *Rhipidomella* sp. (C), *?Tropidoleptus* sp. (C); Pelecypoda: *Grammysia* sp. (P). At 20 feet above base: Brachiopoda: *Mediospififer* sp. (P); Pelecypoda: nuculoid clams (C); Echinodermata: crinoid columns (A)	30.0	308.7
12. Sandstone, very-fine-grained, medium-gray (N5), flow rolls	18.0	278.7
13. Siltstone, medium-dark-gray (N4), thin irregular beds. Blocky weathering, scattered nodules	47.5	260.7
Middle Member		
14. Sandstone, very-fine-grained, medium-gray (N5), flow rolls, nodules. Fossil zones noted: at base: Bryozoa: *Fenestella* sp. (P); Brachiopoda: *Tropidoleptus* sp. (C); Trilobita; *Trimerus* sp. (P); Echinodermata: crinoid columns (C). 13.9 feet above base: Brachiopoda: *Tropidoleptus* sp. (C); Echinodermata: crinoid columns and calyxes with pinnules. 29 feet above base: Brachiopoda: *Tropidoleptus* sp. (C); Pelecypoda: *Grammysia* sp. (P). 38.4 feet above base: Brachiopoda: *Mediospirifer* sp. (C); Echinodermata: crinoid columns (A)	52.0	223.2
15. Claystone, silty, medium-gray (5N), irregular bedding. Very fossiliferous. Brachiopoda: *Spinocyrtia* sp. (C), *Mucrospirifer* sp. (C); *Rhipidomella* sp. (C)	2.2	171.2
16. Sandstone, very-fine-grained, medium-dark-gray (N4), very irregular bedding. Brachiopoda: *Rhipidomella penelope* (C), *Mucrospirifer* sp. (C), *Tropidoleptus* sp. (C).	4.8	169.0
17. Covered	1.0	164.2

Unit	*Unit Thickness*	*Cumulative Thickness*
18. Sandstone, fine-grained, medium-gray (N5), flow rolls. Brachiopoda: spiriferid (C)	4.0	163.2
19. Covered	70.0	159.2
20. Sandstone, very-fine-to fine-grained, medium-gray (N5), nodules	8.1	89.2
21. Covered	62.0	81.1
22. Sandstone, very-fine-grained, medium-gray (N5), flow rolls	19.1	19.1

Summary of measurements:

Millrift Formation (partial):	267.3 feet
Sloat Brook Formation (partial):	373.1 feet
Sparrow Bush Formation (complete):	41.2 feet
Mahantango Formation (partial):	828.8 feet
Upper Member (partial):	605.6 feet
Lower Member (partial):	233.2 feet
Total Section measured:	1510.5 feet

SECTION 5–HAWKS NEST

The steep cliffs on the east side of the Delaware River at Hawks Nest affords an almost complete section of the Delaware River Formation and constitutes its type section. The base is located at the lowest exposures along N. Y. Rte. 97 0.7 mile north of the intersection of N. Y. Rtes. 97 and 42 at a point 1550 feet south of lat. 41°25′00″ N. and 4000 feet east of long. 74°45′00″ W. at an elevation of 680 feet. The section continues northward along the cliffs along N. Y. Rte. 97 to a quarry whose base is at 4000 feet north of lat. 41°25′00″ N. and 3450 feet west of long. 74°45′00″ W. at elevation 800 feet. These localities are in the Port Jervis northwest 7½ minute quadrangle. The attitude of the strata at the base is 40° -12° NW. The dip decreases to 8° at the top. Only approximately 2 percent of this section is covered. The section was measured by Fletcher during 1964.

Unit	*Unit Thickness*	*Cumulative Thickness*
Delaware River Formation		
1. Sandstone, medium-grained, medium-light-gray (N6), parting lineation	12.0	957.2
2. Shale, medium-gray (N5)	4.0	945.2

Unit	*Unit Thickness*	*Cumulative Thickness*
3. Sandstone, medium-grained, medium-light-gray (N6), parting lineation	38.0	941.2
4. Shale, medium-gray (N5)	4.0	903.2
5. Sandstone, medium-grained, medium-light-gray (N6), parting lineation. Parallel laminae	15.0	899.2
6. Shale, medium-gray (N5). 2 foot gray fine-grained sandstone bed 8 feet from base	18.0	884.2
7. Sandstone, coarse-grained, medium-light-gray (N6), cross-bedded	15.0	866.2
8. Sandstone, medium- to coarse grained, medium-light-gray (N6), cross-bedded. Gray shale-pebble conglomerate 8 feet from base	37.0	851.2
9. Shale, medium-gray (N5)	5.0	814.2
10. Sandstone, coarse-grained, medium-light-gray (N6), cross-bedded	50.0	809.2
11. Interbedded claystone, shale, and siltstone, medium-dark-gray (N4) to medium-gray (N5)	24.0	769.2
12. Claystone, medium-gray (N5)	2.0	735.2
13. Sandstone, coarse-grained, medium-light-gray (N6), cross-bedded. Cross-beds are large planar sheets	19.0	733.2
14. Shale, medium-gray (N5)	1.5	714.2
15. Sandstone, medium-grained, medium-light-gray (N6), parting lineation	8.0	712.7
16. Shale, medium-dark-gray (N4)	2.5	704.7
17. Sandstone, medium-grained, medium-light-gray (N6), parting lineation	6.0	702.2
18. Shale, medium-dark-gray (N4)	2.0	676.2
19. Sandstone, coarse-grained, medium-light-gray (N6), cross-bedded	30.0	694.2
20. Shale, medium-gray (N5)	3.0	664.2
21. Sandstone, medium-grained, medium-light-gray (N6), parting lineation	6.0	661.2
22. Interbedded sandstone, medium-grained, medium-light-gray (N6) and shale, medium-dark-gray (N4)	5.0	655.2
23. Sandstone, medium-grained, medium-light-gray (N6), parting lineation	4.0	650.2
24. Shale, medium-gray (N5). Plant fragments	2.0	646.2
25. Sandstone, medium-grained, medium-light-gray (N6), parting lineation	10.2	644.2

Unit	*Unit Thickness*	*Cumulative Thickness*
26. Interbedded sandstone, medium-grained, medium-light-gray (N6) and shale, medium-dark-gray (N4). Wavy bedding	13.0	634.0
27. Shale, medium-gray (N5)	12.0	621.0
28. Interbedded sandstone, medium-grained, medium-light-gray (N6) and shale, medium dark-gray (N4). Thin, gray shale-pebble conglomerates at base and 9 feet from base. Plant fragments	34.0	609.0
29. Sandstone, medium-grained, medium gray (N5). Parallel laminae	15.0	575.0
30. Shale, medium-dark-gray (N4)	1.0	560.0
31. Sandstone, medium-grained, medium-gray (N5). Gray shale pebbles scattered throughout 10 feet 12 feet from base	30.0	559.0
32. Shale, dark gray (N3)	6.0	529.0
33. Sandstone, medium-grained, medium-light gray (N6), parting lineation. Gray shale pebbles scattered through uppermost 7 feet. Plant fragments	11.0	523.0
34. Shale, medium-dark-gray (N4)	3.0	512.0
35. Sandstone, medium-grained, medium-light-gray (N6), parting lineation	8.0	509.0
36. Shale, medium-dark-gray (N4)	2.0	501.0
37. Sandstone, medium-grained, medium-light-gray (N6), parting lineation. Cross-bedded. Plant fragments in lowermost 15 feet	39.0	499.0
38. Shale, medium-dark-gray (N4)	2.0	460.0
39. Interbedded sandstone, medium-grained, medium-light-gray (N6) and shale, medium-dark-gray (N4). Plant fragments at 20 feet from base	41.0	458.0
40. Interbedded sandstone, medium-grained, medium-light-gray (N6) and shale, medium-dark-gray (N4)	6.0	417.0
41. Shale, medium-dark-gray (N4). Wavy bedding	3.0	411.0
42. Sandstone, fine-grained, medium-gray (N5), cross-bedded 25 feet from base, parting lineation, gray shale-pebble conglomerate 25 feet from base. Plant fragments 14 feet from base	43.0	408.0
43. Shale, medium-dark-gray (N4)	3.0	365.0
44. Sandstone, medium-grained, medium- light-gray (N6), parting lineation	13.0	362.0
45. Shale, medium-dark-gray (N4)	2.5	349.0
46. Sandstone, medium-grained, medium-gray (N5). Parallel laminae	7.0	346.5

47. Shale, medium-dark-gray (N4)	15.0	339.5
48. Interbedded sandstone, medium-grained, medium-light-gray (N6) and shale, medium-dark-gray (N4). Plant fragments at 15 feet from base	32.0	324.5
49. Conglomerate, shale and quartz pebbles	1.0	292.5
50. Sandstone, coarse-grained, medium-light-gray (N6)	9.0	291.5
51. Shale, medium-dark-gray (N4)	6.0	282.5
52. Interbedded sandstone, medium-grained, medium-light-gray (N6) and shale, medium-dark-gray (N4). Plant fragments at 10 feet from base	31.0	276.5
53. Shale, medium-dark-gray (N4)	4.0	245.5
54. Sandstone, medium-grained, light-gray (N7), parallel laminae, plant fragments	10.0	241.5
55. Sandstone, fine-grained, medium-light-gray (N6) parallel laminae, partly covered	33.0	231.5
56. Shale, medium-dark-gray (N4)	4.0	198.5
57. Sandstone, medium-grained, medium-light-gray (N6), parting lineation	20.0	194.5
58. Covered. Interval contains some medium-gray (N5), fine-to medium-grained sandstone float and poor exposure	65.0	174.5
59. Sandstone, fine-grained, medium-light-gray (N6) parallel laminae, partly covered	21.0	109.5
60. Sandstone, fine-grained, medium-light-gray (N6), thin and wavy bedding	13.0	88.5
61. Sandstone, fine-grained, medium-light-gray (N6), parallel laminae	49.5	75.5
62. Shale, medium-dark-gray (N4)	1.0	26.0
63. Sandstone, fine-grained, medium-light-gray (N6), parallel laminae	25.0	25.0

Summary of measurements:

Delaware River Formation (partial)	957.2 feet
Total section measured:	957.2 feet

SECTION 6—SECTION AT LOWER SHOHOLA CREEK

A small section of the Shohola Formation was measured in the narrow gorge in Shohola Creek 0.7 mile south of the stream's mouth at a point 200 feet north of lat. 41°47′30″ N. and 150 feet west of long. 74°55′00″ W. at elevation 600 feet in the Milford northwest 7½ minute quadrangle. The strata are nearly horizontal except for a small anticline in unit 1. This section displays excellent joint control of stream drainage.

Unit	*Unit Thickness*	*Cumulative Thickness*
Walton Group		
Shohola Formation		
1. Sandstone, medium-grained, greenish-gray (5 GF 5/1), cross-bedded, ripple marks, parting lineations. Anticline axis approximately 30 feet above base..........	60.0	81.5
2. Claystone and siltstone, grayish-red (5R 4/2). Undulose upper contact...........................	13.0	21.5
3. Sandstone, fine-grained, grayish-red (5R 4/2), rib-and-furrow structures.........................	3.5	8.5
4. Sandstone, fine-grained, greenish-gray (GY 5 5/1), cross-bedded. Units 2 through 4 constitute a fining-upward cycle................................	5.0	5.0

Summary of measurement:

Shohola Formation (partial):	81.5 feet
Total section measured:	81.5 feet

SECTION 7—SECTION AT MIDDLE SHOHOLA CREEK

This section includes strata that display typical features of the Shohola Formation. It is located in Shohola Creek at 6250 feet south of lat. 41°25′00″ N. and 3250 feet west of 74°57′30″ W. at elevation 980 feet in the Milford northwest 7½ minute quadrangle. Local facies changes, trough-type cross-bedding, and a small anticline are well-exposed in this section.

Unit	*Unit Thickness*	*Cumulative Thickness*
Walton Group		
Shohola Formation		
1. Sandstone, fine- to medium-grained, medium-gray (N5) to medium-bluish-gray (5 B 5/1), ripple marks. Thin interbeds of medium- to coarse- grained, medium-gray (5) to greenish-gray (5 GY 5/1) sandstone. Upper 25 feet of unit is cross-bedded. Coarse-grained, pebbly sandstone bed 13 feet above base. Thin gray shale-pebble conglomerate 20 and 25 feet above base......	35.0	80.7
2. Claystone and shale, partly silty, grayish-red (5 R 4/2) and greenish-gray (5 G 5/1) and mottled, mudcracks and burrows. Upper contact with unit 1 is sharp and undulose.....................................	12.3	45.7

3. Shale, silty, greenish-gray (5 GY 5/1). Plant fossils. Grades laterally into unit 2.	5.3	33.4
4. Sandstone, fine-to medium-grained, medium-gray (N5) to greenish-gray (5 GY 6/1), large ripples.	15.6	28.1
5. Sandstone, medium-grained, medium-gray (N5) to greenish-gray (5 GY 6/1), small angular gray shale pebbles. The unit is lenticular and its thickness ranges from 1 to 6 inches.	0.5	12.5
6. Sandstone, medium-grained, medium-light-gray (N6) to greenish-gray (5 GY 6/1). Abundant cross-stratification.	12.0	12.0

Summary of measurements:

Shohola Formation (partial):	80.7 feet
Total Section measured:	80.7 feet

SECTION 8—SECTION AT SHOHOLA FALLS

The section in Shohola Creek at the falls and north of it exposes approximately 110 feet of the Shohola Formation. The top of the section is located in the cliffs along the north side of the Shohola Falls 6100 feet north of lat. 41°22′30″ N. and 3200 feet west of long. 74°57′30″ W. at elevation 1150 feet in the Milford northwest 7½ minute quadrangle. The attitude of the beds is approximately horizontal except for the anticline exposed in the stream banks south of the U. S. Rte. 6 bridge.

Unit	*Unit Thickness*	*Cumulative Thickness*
Walton Group		
Shohola Formation		
1. Sandstone, fine-grained, grayish-red (5 R 4/2).	1.5	111.5
2. Sandstone, fine-grained, greenish-gray (5 GY 5/1) at base and grayish-red (5 R 4/2) at top, cross-bedded, flow rolls at base.	4.0	110.0
3. Shale, medium-gray (N5), fissile, parallel laminae. Grades upward into unit 2.	3.5	106.0
4. Sandstone, medium grained, medium gray (N5) to greenish gray (5 GY 4/1), cross bedded. Bottom contact is sharp and undulose. Plant fossils noted.	8.0	102.5
5. Claystone and shale, partly silty, grayish-red (5 R 4/2 and 10 R 4/2), irregular bedding, tracks and burrows, mud-cracks. This unit forms the lip of Shohola Falls.	22.0	94.5

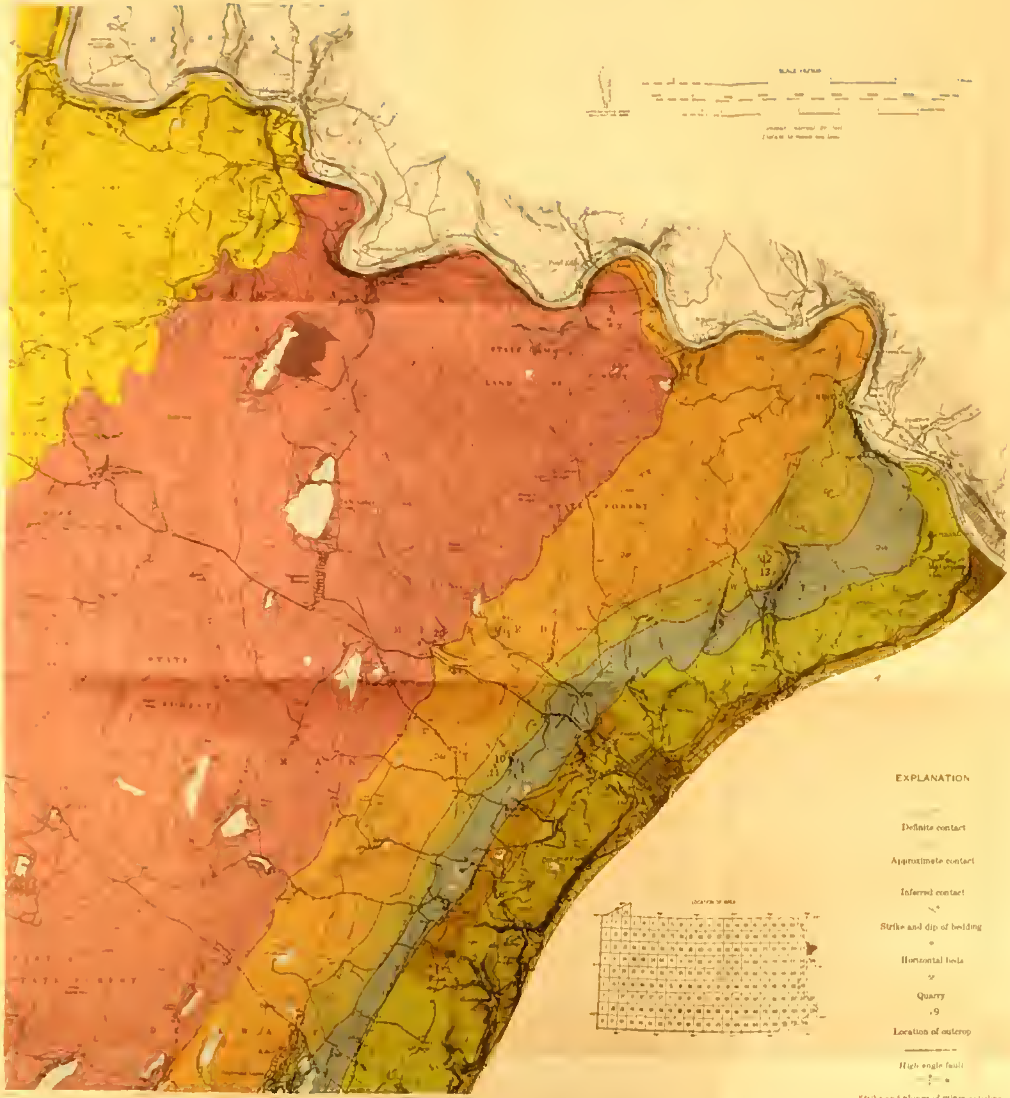
6. Sandstone, fine-grained, mottled grayish-red (5 R 4/2) and greenish-gray (5 GY 4/1), very well indurated, massive bedding, parting lineations	2.0	72.5
7. Sandstone, medium-grained, medium-light-gray (N6) to greenish-gray (5 GY 6/1), scattered gray shale pebbles, cross-bedded. Angular, gray shale-pebble bed three inches thick, one foot from base. Units 5 through 7 constitute a fining-upward cycle. Partly covered	37.9	70.5
8. Sandstone, fine- to medium-grained, medium-gray (N5) to greenish-gray (5 GY 5/1), parallel laminae millimeter thick. Base is sharp and undulose. Grades laterally into a sandy, shale-pebble conglomerate	4.2	32.6
9. Sandstone, fine- to medium-grained, medium-gray (N5) to greenish-gray (5 GY 5/1), cross-bedded. Cross-bedding troughs are contorted	6.0	28.4
10. Conglomerate, shale-pebble, calcareous, cross-bedded. This unit is lenticular	3.5	22.4
11. Sandstone, fine-grained, olive-gray (5 Y 5/1) at base and brownish-gray (5 RY 4/1) at top. Grayish-red (5 R 4/2), siltstone interbeds at top	9.8	18.9
12. Sandstone, fine-grained, siltstone, and silty shale, greenish-gray (5 GY 5/1), parting lineations. Part of this unit eroded	9.1	9.1

Summary of measurements:

Shohola Formation (partial): 111.5 feet

Total section measured: 111.5 feet

2674



Base map from U. S. Geological Survey and Army map service 1:24,000 topographic maps photographically reduced to 1:62,500 by the Pennsylvania Bureau of Topographic and Geologic Survey

EXPLANATION

Definite contact

Approximate contact

Inferred contact

Strike and dip of bedding

Horizontal beds

Quarry

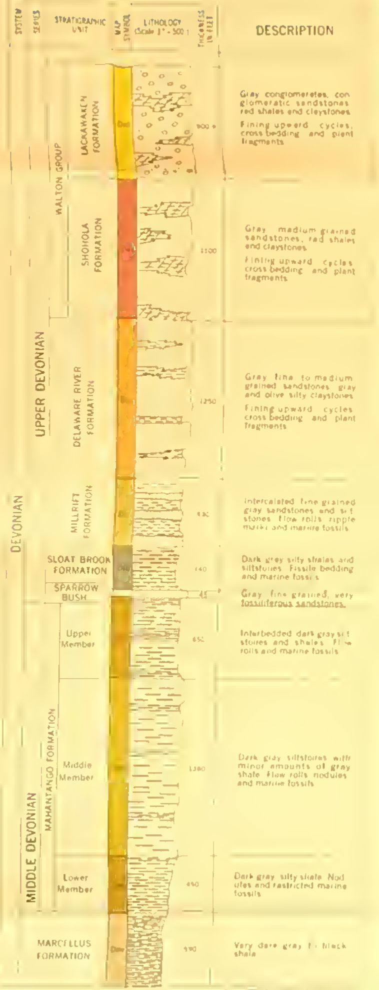
.9

Location of outcrop

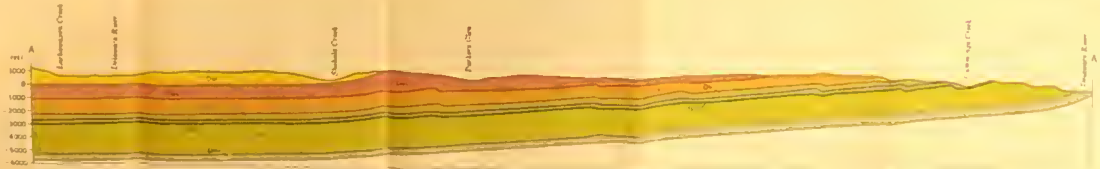
High angle fault

Strike and plunge of minor anticline

Walker Hess #1 well



SYSTEM	SERIES	STRATIGRAPHIC UNIT		MAP SYMBOL	LITHOLOGY (Scale 1" = 500')	THICKNESS IN FEET	DESCRIPTION
DEVONIAN	UPPER DEVONIAN	WALTON GROUP	LACKAWAXEN FORMATION	[illegible]		900 ±	Gray conglomerates, conglomeratic sandstones, red shales and claystones. Fining upward cycles, cross bedding and plant fragments
			SHOHOLA FORMATION	[illegible]		1100	Gray medium grained sandstones, red shales and claystones. Fining upward cycles, cross bedding and plant fragments
		DELAWARE RIVER FORMATION		[illegible]		1250	Gray fine to medium grained sandstones, gray and olive silty claystones. Fining upward cycles, cross bedding and plant fragments
		MILLRIFT FORMATION		[illegible]		430	Intercalated fine grained gray sandstones and siltstones. Flow rolls, ripple marks and marine fossils
		SLOAT BROOK FORMATION		[illegible]		140	Dark gray silty shales and siltstones. Fissile bedding and marine fossils
		SPARROW BUSH				45	Gray fine grained, very fossiliferous sandstones.
	MIDDLE DEVONIAN	MAHANTANGO FORMATION	Upper Member			650	Interbedded dark gray siltstones and shales. Flow rolls and marine fossils
			Middle Member			1300	Dark gray siltstones with minor amounts of gray shale. Flow rolls, nodules and marine fossils
			Lower Member			450	Dark gray silty shale. Nodules and restricted marine fossils
		MARCELLUS FORMATION		Dmr		590	Very dark gray to black shale



Geology by Frank W. Fletcher
and Donald L. Woodrow 1966

GEOLOGIC MAP AND CROSS SECTION OF THE PENNSYLVANIA PORTION OF THE MILFORD AND PORT JERVIS 15 MINUTE QUADRANGLES

SAMPLE LOG OF THE WALKER HESS #1 WELL